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Final Report

ORBIT DIFFERENTIAL CORRECTION – TRACKING PROGRAM

Volume III – Earth Satellite Orbit Prediction Program

George E. Townsend

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Rome Air Development Center
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Griffiss Air Force Base, New York

ORBIT DIFFERENTIAL CORRECTION – TRACKING PROGRAM

Volume III – Satellite Orbit Prediction Program

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FOREWORD

The Space and Information Systems Division (S&ID) of North American Aviation, Inc. (NAA) under Contract AF 30(602)-3638 with the Rome Air Development Center (RADC) of the United States Air Force agreed to perform a 10-month study designed to develop digital computer techniques in two areas of interest to the RADC tracking facility. First, a differential correction geocentric orbit computation program for reducing observed data was to be prepared which would operate in a near-optimum manner at the RADC computer center. Secondly, a computational logic which could be utilized in the tracking process for driving the tracking antennae in an open-loop mode was to be prepared. This second program would employ general perturbations theory in the definition of the predicted trajectory. (This former task is reported in SID 65-1203-1).

This report was prepared as partial documentation of the second task. The contents present the program logic and FØRTRAN listings for the main body of the required program.

The program can be divided operationally into two parts; (1) the trajectory prediction routine and,(2) the tracking routine.

The prediction routine uses a general perturbation theory to assess the first order changes in the osculating elements due to oblateness and drag. No singularities in inclination or eccentricity are present in the formulation which is taken from the work of Anthony G. Lubowe (Appendix I).

The tracking routine has been designed to accept as many as ten active stations and to output range, range-rate, azimuth and elevation data for any station viewing the satellite.

This contract has been managed at NAA S&ID by Mr. J. A. Hill and directed by Mr. G. E. Townsend. J. C. Mendez, assisted by Mr. Townsend, designed the rationale for the program, coded the major portion of the logic, performed the preliminary checks of the operation, and prepared this document.

The assistance offered by RADC personnel under the direction of Mr. Gordon Negus (Program Manager) is gratefully acknowledged.

ABSTRACT

This document presents the formulation, computational logic, and coding information developed for the purpose of tracking an artificial earth satellite in an open-loop mode. The program was developed as a FØRTRAN IV, IBM 7094 program which uses the standard North American Aviation monitor system (NAASYS version 13). The logic presented is intended for use in developing a similar program for the Packard Bell 250 digital computer.

The trajectory prediction portion of the program is a general perturbation formulation developed by Anthony G. Lubowe of Bell Telephone Laboratories. The tracking portion of the program can accept as many as ten tracking stations and outputs range, range-rate, azimuth and elevation data.

CONTENTS

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* documented in SID 65-1203-1

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APPENDIX I AND II DELETED

FIGURES

INTRODUCTION

This program is designed to track an artificial earth satellite in an open-loop mode on a Packard Bell 250 computer. Accordingly, the program can be considered to perform two major tasks:

1. Prediction of the satellite's position and velocity vectors, and
2. Interrogation of the active tracking stations.

Functionally, the program consists of two driving routines:

1. PØSVEL drives the prediction routine, and
2. TRAK drives the tracking routine.

Efforts have been made to insure a high level of internal consistency throughout the program. Particular care has been taken with the iteration on Kepler's equation and with the logic for computing and storing the changes to the orbital elements.

The formulation for the prediction routine has been selected to eliminate singularities at the critical inclination, and at low (or zero) inclinations, and/or eccentricities; it has been taken from a paper by Anthony G. Lubowe which is reporduced in Appendix I.

Briefly, the theory is as follows: a set of non-singular osculating elements is computed from the initial position, velocity, and time; the non-singular elements replace the more traditional set (a, e, i, ω, Ω, τ) which leads to the above noted singularities. The selected non-singular elements are:

$$
\begin{aligned}
a &= a \\
\mu &= e \sin\tilde{\omega} = e \sin(\omega + \Omega) \\
\nu &= e \cos\tilde{\omega} \\
p &= \sin i \sin\Omega \\
q &= \sin i \cos\Omega \\
\tau &= t - \frac{\tilde{\omega}}{\bar{n}}
\end{aligned}
$$

First order perturbations to these elements due to oblateness and drag have been included. Higher order terms, i.e., order J^2, H, K have been dropped. Lagrange's Planetary Equation's form the basis for the oblateness perturbation theory. These equations express the orbit of a body experiencing a perturbing force in terms of the deviations of the orbital elements from those describing the unperturbed orbit. They are six first-order differential equations with time as the independent variable. The independent variable is transformed from time to the angle theta, in the unperturbed orbit (θ = longitude of perigee + true anomoly). The six differential equations can then be integrated between θ_0 and θ_1 by holding the orbital elements constant over the interval of integration. The result is a first order approximation to the changes in the elements due to the perturbations considered.

The perturbations due to drag have been taken from work by T. E. Sterne. A description of the work has been included in Appendix II; the description originally appeared in the Orbital Handbook, NASA SP-33, Part 1, Volume I.

Input data for the program consists of geocentric position and velocity vectors (rectangular coordinates), the corresponding whole number of days past zero hours, 1 January 1950, and the fractional part of a day. Due to approximations in the formulation and the limited duration (less than 10 days) of most applications, no correction for motion of the vernal equinox has been included. Thus, the program operates in a rectangular equatorial coordinate system tied to the true equinox of the date of the initial conditions. Further required input are the step size in seconds (i.e., the interval between consecutive predictions of position and velocity), the final elapsed time, the W/C_DA and tracking station data. The main program (MAIN) reads the input data and drives the program. The prediction of trajectory points is accomplished in subroutine PØSVEL. During the first pass, the initial osculating elements are computed and stored; in subsequent passes, this operation is skipped. Then the changes to the osculating elements due to first-order oblateness and drag perturbations are computed. To preserve maximum accuracy, these changes are stored in running sums. These running sums are added to the original elements at each step rather than adding the changes to the elements at each step. The predicted position and velocity vectors are then computed using the updated elements. The prediction has now been accomplished and control is returned to the main program.

Main next calls the tracking routine (subroutine TRAK) which computes the local hour angle and the up, east, and north unit vectors at the tracking site, as well as the position and velocity vectors of the tracking site. The position and velocity vectors of the satellite relative to the tracking site can then be computed by vector subtraction. Finally, range, range-rate, azimuth and elevation data are calculated. At this point, control is again returned to the main program.

Now, the prediction and tracking cycle is complete, and the elapsed time is checked to determine whether the program should continue or terminate the computation. Care has been exercised to assure that these operations can be performed in small fractions of a second on the IBM 7094 and that operation times on smaller computers (e.g., the Packard Bell 250) will be reasonable. As a result, the real-time capability required for tracking is obtainable.

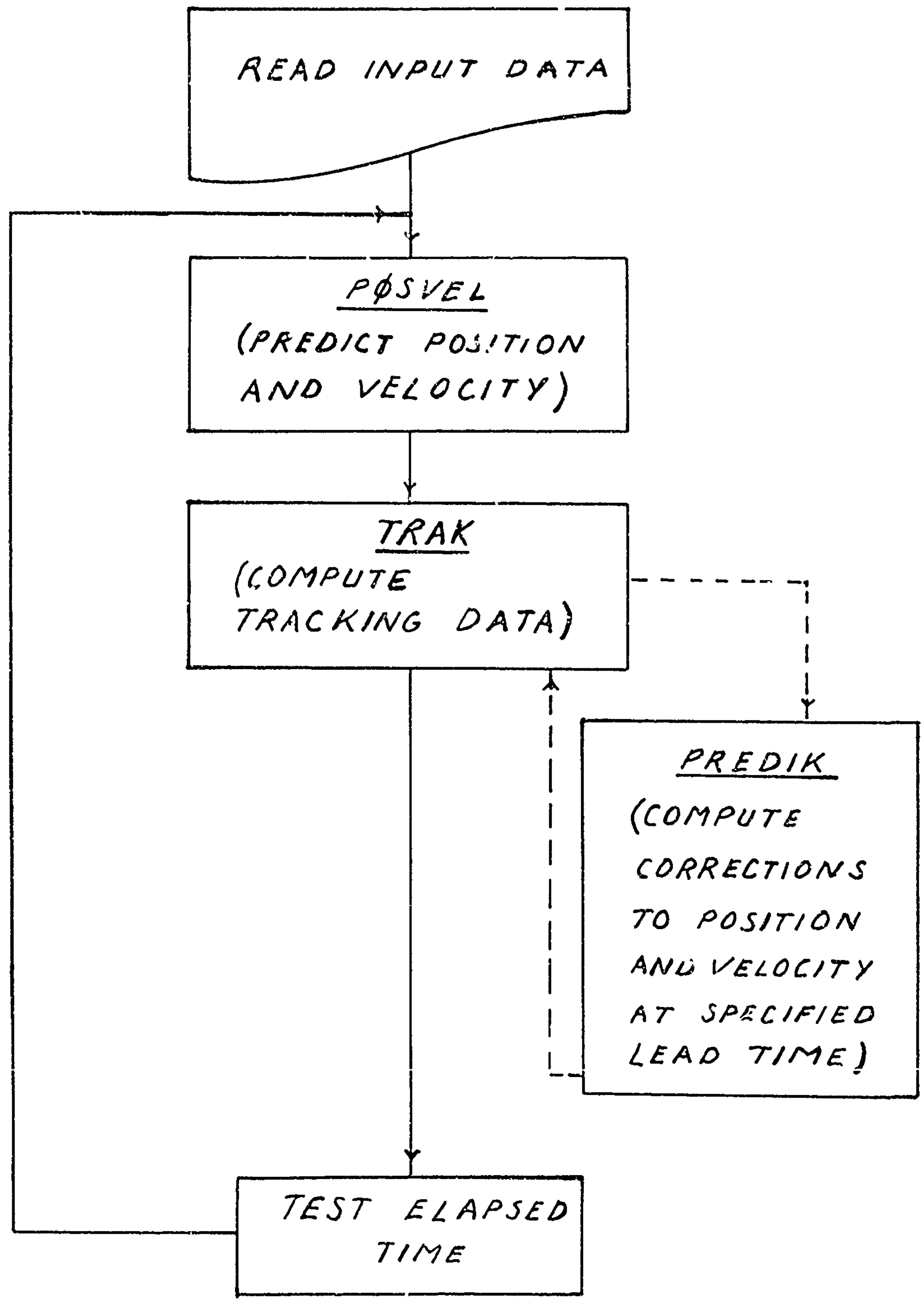
Also included in this documentation is the logic necessary to differentially correct the position and velocity vectors based on a set of observations. The rationale for this process involves the reduction of a set of observed minus computed residuals; and the prediction of a corrected set of position and velocity vectors at some future time. To be specific, the weighted least-squares process is used to produce agreement between a set of nine observations (R, A, E, acquired at three epochs) and the corresponding computed values at the specified lead time. This logic has not been included in the program because the acquisition and method of input of the nine observations depend on the tracking and computing hardware used. It is epxected, however, that the observation data array would be constructed in, and the differential corrections driver routine (PREDIK) would be called from TRAK; then the computed

corrections would be added to the computed position and velocity vectors at the lead time and a flag raised. When control was returned to the main program, the flag would indicate that a corrected position and velocity were available; the corresponding "corrected" osculating elements would be computed, and the computation would proceed as before.

It should be noted that the lead time must be great enough to allow real-time computation.

The following diagram indicates the program operation schematically.

SCHEMATIC OF PROGRAM LOGIC



The following pages describe the purpose, formulation, etc. of each subroutine.

Subroutine BLØCK DATA

Purpose: To read block data into name common

Deck Name: BLØCK

Subroutines Called: NONE

Functions Called: NONE

Deck Length: 00001_8

Input/Output:

I/O	FØRTRAN Name	Math Name	Dimension	Common/ Argument	Definition
Ø	GCØN	k_E	1	ASTRØ	gravitational constant of the Earth
Ø	AJ	J	1	ASTRØ	first term in the Earth's gravitational potential
Ø	RE	R_E	1	ASTRØ	Earth's equatorial radius
Ø	RP	R_P	1	ASTRØ	Earth's polar radius
Ø	ALT	A_l	1	ATMØS	lowest altitude tabulated in density
Ø	STEP	S	1	ATMØS	distance between altitudes in density table
Ø	DENS(M)	ρ_M	36	ATMØS	tabulated values of density

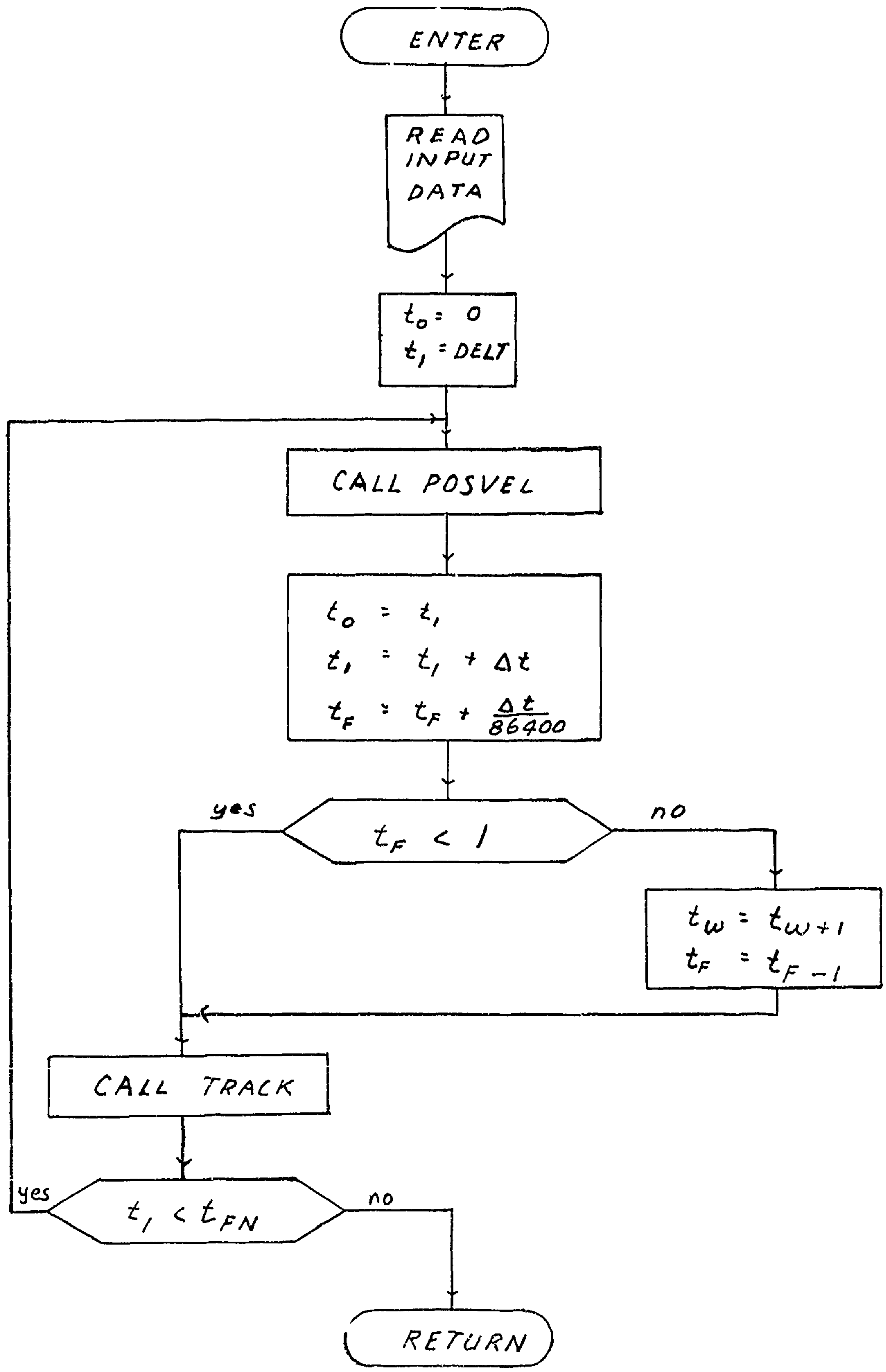
```
     BLOCK         -  EFN   SOURCE STATEMENT  -  IFN(S)  -

      BLOCK DATA                                                       BLK00010
      COMMON  /ATMOS/ ALT,STEP,DENS(36)                                BLK00020
      COMMON /ASTRO/ GCON,AJ,RE,RP                                     BLK00030
      DATA  GCON,AJ,RE,RP  /1.4076450E16, .00162345, 2.0925741E7,      BLK00040
     1 2.0855591E7/                                                    BLK00050
      DATA ALT,STEP /500 000.,  30 000./                               BLK00060
      DATA (DENS(L), L=1,36)        /1.090E-10 ,6.822E-11 ,4.906E-11 ,BLK00070
     13.676E-11 ,2.796E-11 ,2.177E-11 ,1.713E-11 ,1.359E-11 ,1.086E-11 ,BLK00080
     28.765E-12 ,7.135E-12 ,5.838E-12 ,4.800E-12 ,3.965E-12 ,3.290E-12 ,BLK00090
     32.742E-12 ,2.294E-12 ,1.933E-12 ,1.634E-12 ,1.386E-12 ,1.179E-12 ,BLK00100
     41.006E-12 ,8.607E-13 ,7.384E-13 ,6.351E-13 ,5.476E-13 ,4.734E-13 ,BLK00110
     54.102E-13 ,3.572E-13 ,3.116E-13 ,2.742E-13 ,2.385E-13 ,2.092E-13 ,BLK00120
     61.838E-13 ,1.618E-13 ,1.426E-13/                                 BLK00130
      END                                                              BLK00140
```

```
       BLOCK                                   STORAGE  MAP

                                                BLOCK  DATA

                                          COMMON   VARIABLES

               COMMON BLOCK      ATMOS              ORIGIN      00000           LENGTH      00046

SYMBOL       LOCATION      TYPE      SYMBOL      LOCATION      TYPE      SYMBOL      LOCATION      TYPE
ALT           00000         R        STEP         00001         R        DENS         00002         R

               COMMON BLOCK      ASTRO              ORIGIN      00046           LENGTH      00004
GCON          00000         R        AJ           00001         R        RE           00002         R
RP            00003         R
  DECK LENGTH IN OCTAL IS     00001.
```

MAIN ROUTINE

Purpose:	Main routine
Deck Name:	MAIN
Subroutines Called:	PØSVEL (prediction logic) TRAK (tracking logic)
Functions Required:	None
Deck Length:	00515_8
Method:	MAIN reads input data, calls PØSVEL and TRAK in sequence and exercises control over continue or terminate decision.

MAIN FLOW CHART



```
C                                                                      MNC00010
C        THIS ROUTINE DRIVES THE PROGRAM.  THE MAIN SUBROUTINE GROUPINGSMN000020
C        CALLED ARE                                                    MNC00030
C          1. PREDCT     COMPUTES THE PREDICTED POSITION AND VELOCITY  MN000040
C                        VECTORS AT TIME T1.   PREDCT USES A GENERAL   MN000050
C                        PERTURBATIONS APPROACH TO COMPUTE THE CHANGES MN000060
C                        IN THE OSCULATING ELEMENTS OVER TIME T1 - TO. MN000070
C          2. TRAK       COMPUTES TRACKING DATA FOR AS MANY AS TEN     MN000080
C                        TRACKING STATIONS.  RANGE, RANGE-RATE, AZIMUTH MN000090
C                        AND ELEVATION ARE COMPUTED.                   MN000100
C                                                                      MN000110
      DIMENSION RVEC(3), VVEC(3), RNEW(3), VNEW(3)                     MN000120
C                                                                      MN000130
      COMMON /TRAST/ STATN(40), HORCOR(10)                             MN000140
      COMMON /ASTRO/ GCON, AJ, RE, RP                                  MN000150
C                                                                      MN000170
    5 READ (5,10) RVEC,VVEC,TW,TF,DELT,TFN,WCDA,XTRAK                  MN000180     1
   10 FORMAT (6E12.8)                                                  MN000190
      NUMBER = XTRAK                                                   MN000200
      DO 20 J=1,NUMBER                                                 MN000202
      K = 4*J - 3                                                      MN000204
      READ (5,15) STATN(K+3),STATN(K+1),STATN(K),STATN(K+2),HORCOR(J)  MN000206     8
   20 CONTINUE                                                         MN000208
   15 FORMAT (A6, 6X, 4E12.8)                                          MN000210
C                                                                      MN000200
      WRITE (6,7000)                                                   MNC00212    16
 7000 FORMAT ( 11H1INPUT DATA   / 9H-   X (FT) 8X   4H    Y  13X   4H    Z 13XMN000214
     1 13H   XDOT (FPS)   4X   7H    YDOT 10X   7H    ZDOT   /         MN000216
     2  17H    TIME (WH DAYS)   17H    TIME (FR DAYS)   17H    D TIME (SEC)  MN000218
     3 17H    FNL TIME (SEC)   17H    WCDA (LB/FT2)   17H    NO OF STATIONSMN000220
     4 )                                                               MN000222
      WRITE (6,7001) RVEC,VVEC,TW,TF,DELT,TFN,WCDA,NUMBER              MN000224    17
 7001 FORMAT (/    6E17.8 / 5E17.8,I17)                                MN000226
      WRITE (6,7002)                                                   MN000228    20
 7002 FORMAT (1H- / 1H-    32HTRACKING STATION DATA    (DEG,FT)    //  MM000230
     1 8X   4HNAME   4X   13HLONG (+ EAST)   4X   13HLAT (+ NORTH)   9X     MN000232
```

```
    2  8HALTITUDE  7X  10HHORIZ CORR / 1H  )                    MN000234
      DO 7007  L = 1,NUMBER                                    MN000236
      K   =  4*L - 3                                           MN000238
      WRITE (6,7003) STATN(K+3), STATN(K+1), STATN(K), STATN(K+2), MN000240
    1 HORCOR(L)                                                MN000242    24
 7007 CONTINUE                                                 MN000244
 7003 FORMAT (6X, A6, 4E17.8)                                  MN000246
C                                                              MN000270
      MCAK    = 1                                              MN000280
      TO      = 0.                                             MN000290
      T1      = DELT                                           MN000300
C                                                              MN000310
C        COMPUTE PREDICTED VALUES OF POSITION AND VELOCITY AT TIME T1.  MN000320
C                                                              MN000330
  200 CALL POSVEL (RVEC,VVEC,RNEW,VNEW,TO,T1,WCDA,MONK)        MN000340
C                                                              MN000350    35
      TF      = TF + DELT/86400.                               MN000380
      IF (TF .LT. 1.) GO TO 300                                MN000390
      TW      = TW + 1.                                        MN000400
      TF      = TF - 1.                                        MN000410
  300 TO    = T1                                               MN000360
      IF (T1 .GE. 650000.) DELT = 60.
      T1    = T1 + DELT                                        MN000370
C                                                              MN000420
C        COMPUTE TRACKING DATA                                 MN000430
C                                                              MN000440
  360 CALL TRAK  (RNEW,VNEW,TW,TF,NUMBER)                      MN000450
C                                                              MN000460    44
      IF (T1 .LT. TFN) GO TO 200                               MN000470
C                                                              MN000480
      GO TO 5                                                  MN000490
      END                                                      MN000500
```

SID 65-1203-3

STORAGE MAP

MAIN PROGRAM

COMMON VARIABLES

COMMON BLOCK TRAST ORIGIN 00001 LENGTH 00062

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
STATN	C0000	R	HORCOR	00050	R			

COMMON BLOCK ASTRO ORIGIN 00063 LENGTH 00004

GCON	000C0	R	AJ	00001	R	RE	00002	R
RP	00003	R						

DIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
RVEC	00067	R	VVEC	00072	R	RNEW	00075	R
VNEW	00100	R						

UNDIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
TW	00103	R	TF	00104	R	DELT	00105	R
TFN	00106	R	WCDA	00107	R	XTRAK	C0110	R
NUMBER	00111	I	J	00112	I	K	00113	I
L	00114	I	MONK	00115	I	TO	00116	R
T1	00117	R						

ENTRY POINTS

...... SECTION 7

MAIN STORAGE MAP

SUBROUTINES CALLED

.FRDD.	SECTION	8	.FSLI.	SECTION	9	.FWRD.	SECTION	10
.FSLO.	SECTION	11	POSVEL	SECTION	12	TRAK	SECTION	13
.UNO5.	SECTION	14	.FRTN.	SECTION	15	.FCNV.	SECTION	16
.UNC6.	SECTION	17	.FFIL.	SECTION	18	CC.1	SECTION	19
CC.2	SECTION	20	CC.3	SECTION	21	CC.4	SECTION	22
SYSLOC	SECTION	23						

EFN IFN CORRESPONDENCE

EFN	IFN	LOCATION	EFN	IFN	LOCATION	EFN	IFN	LOCATION
5	1A	00262	10	FORMAT	00135	20	14A	00367
15	FORMAT	00137	7000	FORMAT	00142	7001	FORMAT	0?216
7002	FORMAT	00223	7007	30A	00505	7003	FORMAT	00257
200	34A	00514	300	40A	00547	360	43A	00562

DECK LENGTH IN OCTAL IS 00530.

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Subroutine PØSVEL

Purpose: This routine computes the predicted position and velocity vectors at time t_1.

Deck Name: PØSVL

Calling Sequence: CALL PØSVEL (RVEC, VVEC, RNEW, VNEW, TØ, T1, MØNK)

Subroutines Required:
- ØSCUL (computes osculating elements)
- THET (computes theta for a given time)
- DØBL (computes oblateness perturbation)
- DRAG (computes drag perturbation)
- VECT (computes position and velocity vectors)

Functions Required: NONE

Deck Length: 512_8

Input/Output:

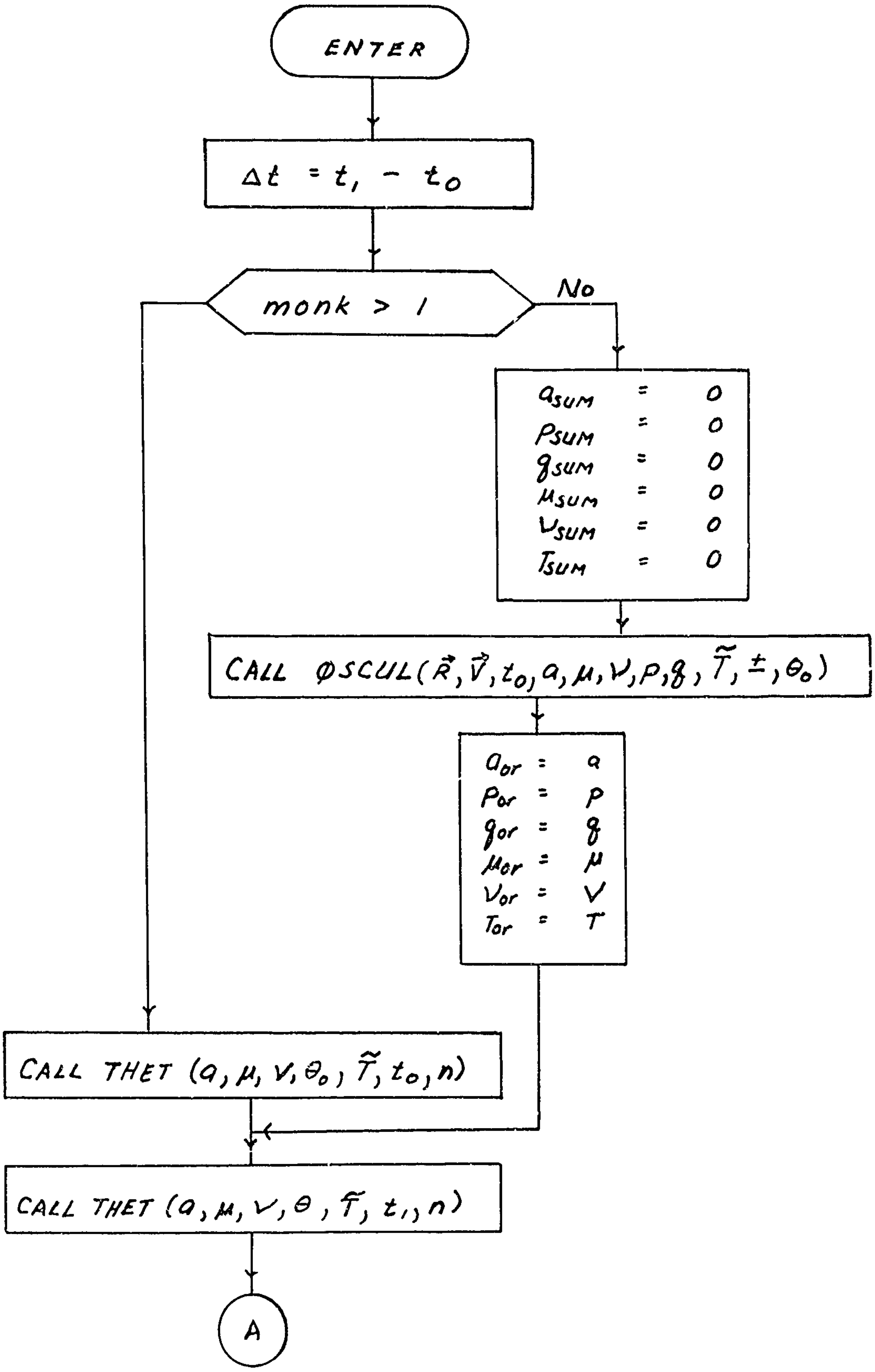
I/O	FØRTRAN Name	Math Name	Dimension	Common/ Argument	Description
I	RVEC	$\vec{R}$	3	Arg	current position vector
I	VVEC	$\vec{V}$	3	Arg	current velocity vector
Ø	RNEW	$\vec{R}_N$	3	Arg	predicted position vector
Ø	VNEW	$\vec{V}_N$	3	Arg	predicted velocity vector
I	TØ	t_o	1	Arg	current time
I	TI	t_i	1	Arg	time of prediction
I	WCDA	$\frac{W}{C_D A}$	1	Arg	W = spacecraft weight C_D = drag coefficient A = cross sectional area
I	MØNK		1	Arg	index = 1 for first pass through, 2 for subsequent passes

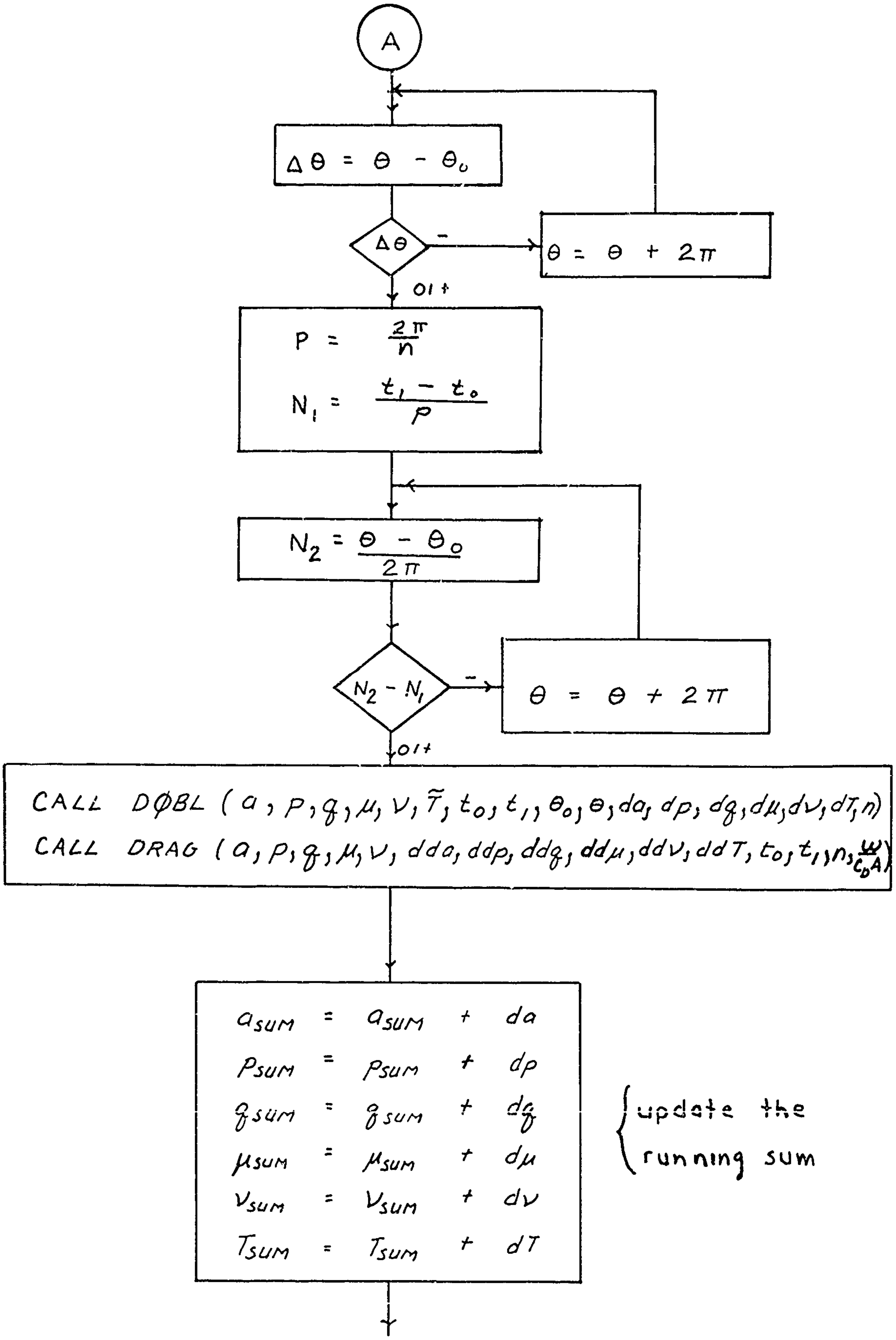
Description of Equations:

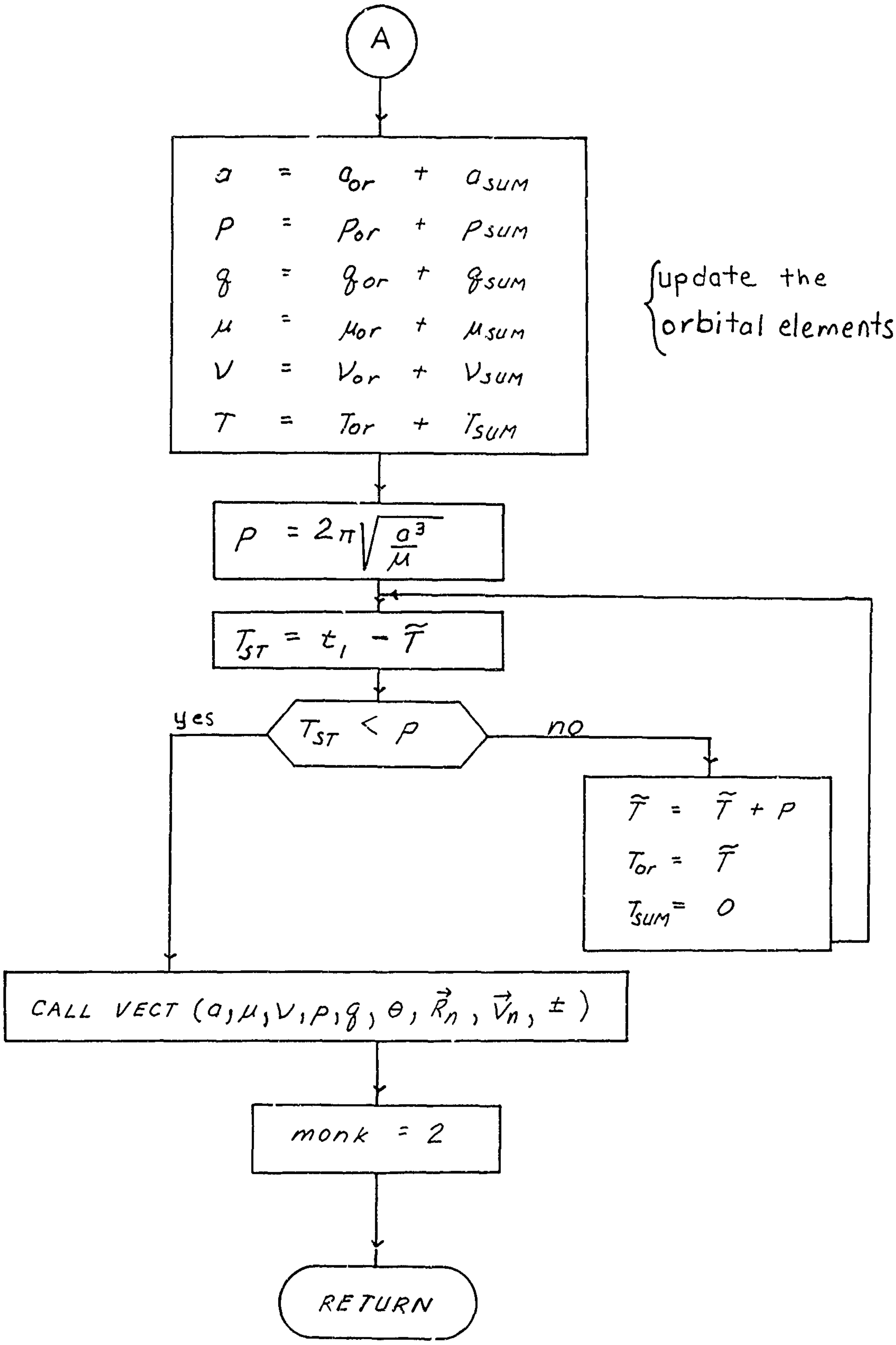
This routine predicts the satellite's position and velocity vectors at a specified time. PØSVEL is called each time the position and velocity are to be predicted; when the prediction has been made, control is returned to the main program.

During the first pass, the running sums of the perturbations to the elements are set equal to zero. ØSCUL is called to compute the orbital elements and the original values of the orbital elements are stored. During subsequent passes, this computation is omitted and the updated elements are used to compute the current value of theta. Then, in both the first and later passes, the value of theta at the prediction time is computed (in subroutine THET). Next, the changes in the osculating elements due to oblateness (subroutine DØBL) and drag (subroutine DRAG) are computed and the running sums of perturbations to the elements are updated. The updated running sums are added to the original values of the osculating elements at the prediction time. These values are used to compute the satellite's position and velocity vectors (in subroutine VECT).

SUBROUTINE PØSVEL




A
Δθ = θ − θ₀
Δθ
−
θ = θ + 2π
0 / +
P = 2π / n
N₁ = (t₁ − t₀) / P
N₂ = (θ − θ₀) / 2π
N₂ − N₁
−
θ = θ + 2π
0 / +
CALL DØBL (a, p, q, μ, ν, T̃, t₀, t₁, θ₀, θ, da, dp, dq, dμ, dν, dT, n)
CALL DRAG (a, p, q, μ, ν, dda, ddp, ddq, ddμ, ddν, ddT, t₀, t₁, n, W/C_D A)
a_SUM = a_SUM + da
p_SUM = p_SUM + dp
q_SUM = q_SUM + dq
μ_SUM = μ_SUM + dμ
ν_SUM = ν_SUM + dν
T_SUM = T_SUM + dT
update the running sum


A
a = a_or + a_SUM
p = p_or + p_SUM
q = q_or + q_SUM
μ = μ_or + μ_SUM
V = V_or + V_SUM
T = T_or + T_SUM
update the orbital elements
P = 2π√(a³/μ)
T_ST = t_1 − T̃
T_ST < P
yes
no
T̃ = T̃ + P
T_or = T̃
T_SUM = 0
CALL VECT (a, μ, V, p, q, θ, R⃗_n, V⃗_n, ±)
monk = 2
RETURN

```
      POSVL       -  EFN   SOURCE STATEMENT  -  IFN(S)  -

      SUBROUTINE POSVEL (RVEC,VVEC,RNEW,VNEW,TO,T1,WCDA,MUNK)          PSVL0010
C                                                                      PSVL0020
C       THIS IS A GENERAL PERTURBATION PROGRAM THAT PREDICTS          PSVL0030
C       POSITION AND VELOCITY OF A SPACECRAFT IN AN EARTH ORBIT.  THE PSVL0040
C       FORMULATION IS BASED ON LAGRANGE'S PLANETARY EQUATIONS AND IS PSVL0050
C       VALID FOR LOW ECCENTRICITY AND LOW INCLINATION ORBITS.  THE   PSVL0060
C       PROGRAM IS FIRST ORDER IN THE SENSE THAT TERMS OF ORDER J2**2, PSVL0070
C       J3, AND J4 HAVE BEEN DROPPED  SECULAR AND PERIODIC TERMS      PSVL0080
C       LINEAR IN J2 HAVE BEEN RETAINED.                              PSVL0090
C                                                                      PSVL0100
C       THE FORMULATION HAS BEEN TAKEN FROM                            PSVL0110
C            LUBOWE, ANTHONY G.                                        PSVL0120
C           WITH LOW ECCENTRICITIES, OR LOW INCLINATIONS, OR BOTH.'   PSVL0130
C           'APPLICATION OF LAGRANGE'S PLANETARY EQUATIONS TO ORBITS  PSVL0140
C            JOURNAL OF THE ASTRONAUTICAL SCIENCES, VOL. XII, NO. 1,  PSVL0150
C            PAGES 7-17, SPRING, 1965.                                 PSVL0160
C                                                                      PSVL0170
C       THE ORBITAL ELEMENTS HAVE BEEN CHOSEN TO ELIMINATE 'LOW E'    PSVL0180
C       AND/OR 'LOW I' SINGULARITIES.   THEY ARE                      PSVL0190
C           A       = SEMI MAJOR AXIS                                  PSVL0200
C           MU      = E * SIN(W)                                       PSVL0210
C           NU      = E * COS(W)                                       PSVL0220
C           P       = SIN(I) * SIN(OMEGA)                              PSVL0230
C           Q       = SIN(I) * CCS(OMEGA)                              PSVL0240
C           TCAP    = 'TIME OF EQUINOX PASSAGE'                        PSVL0250
C       WHERE                                                          PSVL0260
C           E       = ECCENTRICITY                                     PSVL0270
C           W       = LONGITUDE OF PERIGEE                             PSVL0280
C           I       = INCLINATION                                      PSVL0290
C           OMEGA   = RIGHT ASCENSION OF ASCENDING NODE                PSVL0300
C                                                                      PSVL0310
C       FURTHER NOMENCLATURE                                           PSVL0320
C           TO      = ORIGINAL TIME                                    PSVL0330
C           T1      = TIME OF PREDICTION                               PSVL0340
```

SID 65-1203-3

```
       POSVL       -  EFN   SCURCF STATEMENT  -  IFN(S)  -

C          THETA   = F + W   = LONGITUDE IN THE ORBIT                PSVL0350
C          F       = TRUE ANOMOLY                                    PSVL0360
C          RVEC    = POSITION VECTOR                                 PSVL0370
C          VVEC    = VELOCITY VECTOR                                 PSVL0380
C          MONK    = 1 FOR THE FIRST PASS THROUGH                    PSVL0390
C                  = 2 FOR SUBSEQUENT PASSES                         PSVL0400
C          THE SUFFIX 'NEW' ATTACHED TO ANY VARIABLE INDICATES THE   PSVL0410
C          PREDICTED VALUE OF THE VARIABLE (AT TIME T1).             PSVL0420
C                                                                    PSVL0430
C                                                                    PSVL0440
      REAL MSUM,NSUM,MOR,NOR,MU,NU,NMOT,MMU,NNU                      PSVL0450
C                                                                    PSVL0460
      DIMENSION RVEC(3), VVEC(3), RNEW(3), VNEW(3)                   PSVL0470
      DIMENSION RNM(3), VKM(3)                                       PSVL0480
C                                                                    PSVL0490
      COMMON /ASTRC/ GCON,AJ,RE,RP                                   PSVL0500
      DATA   TWOPI /6.2831853/                                       PSVL0510
      DELT = T1 - TO                                                 PSVL0520
C                                                                    PSVL0530
      IF (MONK .GT. 1) GO TO 60                                      PSVL0540
C                                                                    PSVL0550
C        INITIALIZE THE RUNNING SUM                                  PSVL0560
C                                                                    PSVL0570
      ASUM   = 0.                                                    PSVL0580
      PSUM   = 0.                                                    PSVL0590
      QSUM   = 0.                                                    PSVL0600
      MSUM   = 0.                                                    PSVL0610
      NSUM   = 0.                                                    PSVL0620
      TSUM   = 0.                                                    PSVL0630
C                                                                    PSVL0640
C        COMPUTE OSCULATING ELEMENTS AT TIME T-ZERO                   PSVL0650
C                                                                    PSVL0660
      CALL OSCUL (RVEC,VVEC,TO,A,MU,NU,P,Q,TCAP,SGN,THETAO)          PSVL0670    5
      WRITE (6,9001) A,MU,NU,P,Q,TCAP,THETAO                         PSVL0680    6
 9001 FORMAT (//  40H OSCUL OUTPUT - A,MU,NU,P,Q,TCAP,THETAO / 7E17.8) PSVL0690
```

```
       POSVL        -  EFN   SOURCE STATEMENT  -  IFN(S)  -
C                                                               PSVL0700
C         STORE ORIGINAL VALUES OF ORBITAL ELEMENTS             PSVL0710
C                                                               PSVL0720
      AOR     = A                                               PSVL0730
      POR     = P                                               PSVL0740
      QOR     = Q                                               PSVL0750
      MOR     = MU                                              PSVL0760
      NOR     = NU                                              PSVL0770
      TOR     = TCAP                                            PSVL0780
      GO TO 70                                                  PSVL0790
C                                                               PSVL0800
C                                                               PSVL0810
C         COMPUTE THETA  =  LONGITUDE IN THE ORBIT              PSVL0820
C                                                               PSVL0830
   60 CALL THET (A,MU,NU,THETAO,TCAP,TO,NMOT)                   PSVL0840    9
   70 CALL THET (A,MU,NU,THETA ,TCAP,T1,NMOT)                   PSVL0850
C                                                               PSVL0860
C         INSURE THAT THETA IS GREATER THAN THETAO.  IN CASE THE      PSVL0870
C         PREDICTED POINT IS GREATER THAN ONE REVOLUTION AWAY FROM THE PSVL0880
C         BASE POINT, INSURE THAT THETA IS THE CORRECT NUMBER OF      PSVL0890
C         REVOLUTIONS FROM THETAO.                              PSVL0900
C                                                               PSVL0910   11
   75 DTHET   = THETA - THETAO                                  PSVL0920
      IF (DTHET) 80, 85, 85                                     PSVL0930
   80 THETA   = THETA + TWOPI                                   PSVL0940
      GO TO 75                                                  PSVL0950
C                                                               PSVL0960
   85 PERIOD = TWOPI / NMOT                                     PSVL0970
      NREV1   = (T1-TO) / PERIOD                                PSVL0980
  100 NREV2   = (THETA-THETAO) / TWOPI                          PSVL0.90
      IF (NREV2 - NREV1) 105, 110, 110                          PSVL1000
  105 THETA   = THETA + TWOPI                                   PSVL1010
      GO TO 100                                                 PSVL1020
  110 CONTINUE                                                  PSVL1030
C                                                               PSVL1040
C                                                               PSVL1050
C                                                               PSVL1060
```

```
        POSVL      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

C        COMPUTE CHANGES IN THE OSCULATING ELEMENTS DUE TO THE           PSVL1070
C        OBLATENESS AND DRAG PERTURBATIONS.                              PSVL1080
C                                                                        PSVL1090
      CALL DOBL (A,P,Q,MU,NU,TCAP,TO,T1,THETAO,THETA,DA,DP,DQ,DM,DN,DT,  PSVL1100
     1 NMOT)                                                             PSVL1110
C                                                                        PSVL1120   23
      CALL DRAG (A,P,Q,MU,NU,DDA,DDP,DDQ,DDM,DDN,DDT,TO,T1,NMOT,WCDA)    PSVL1130
C                                                                        PSVL1140
C        CONTINUE THE RUNNING SUM OF THE PERTURBATIONS TO THE            PSVL1150
C        OSCULATING ELEMENTS.                                            PSVL1160
C                                                                        PSVL1170   25
      ASUM   = ASUM + DA + DDA                                           PSVL1180
      PSUM   = PSUM + DP + DDP                                           PSVL1190
      QSUM   = QSUM + DQ + DDQ                                           PSVL1200
      MSUM   = MSUM + DM + DDM                                           PSVL1210
      NSUM   = NSUM + DN + DDN                                           PSVL1220
      TSUM   = TSUM + DT + DDT                                           PSVL1230
C                                                                        PSVL1240
C        COMPUTE THE PERTURBED VALUES OF THE ORBITAL ELEMENTS            PSVL1250
C                                                                        PSVL1260
      A      = AOR + ASUM                                                PSVL1270
      P      = POR + PSUM                                                PSVL1280
      Q      = QOR + QSUM                                                PSVL1290
      MU     = MOR + MSUM                                                PSVL1300
      NU     = NOR + NSUM                                                PSVL1310
      TCAP   = TOR + TSUM                                                PSVL1320
      PERIOD = TWOPI * SQRT (A**3/GCON)                                  PSVL1330   27
  290 TEST   = T1 - TCAP                                                 PSVL1340
      IF (TEST .LT. PERIOD) GO TO 300                                    PSVL1350
      TCAP   = TCAP + PERIOD                                             PSVL1360
      TOR    = TCAP                                                      PSVL1370
      TSUM   = 0.                                                        PSVL1380
      GO TO 290                                                          PSVL1390
C                                                                        PSVL1400
  300 CONTINUE                                                           PSVL1410
C                                                                        PSVL1420
C        COMPUTE POSITION AND VELOCITY VECTORS                           PSVL1430
```

```
          POSVL         -  EFN    SOURCE STATEMENT  -  IFN(S)  -

C                                                                         PSVL1440
      CALL VECT (A,MU,NU,P,Q,THETA,RNEW,VNEW,SGN)                         PSVL1450
C                                                                         PSVL1460    34
      DO 9009 J = 1,3                                                     PSVL1470
      VKM(J) = VNEW(J) * .0003048                                         PSVL1480
 9009 RNM(J) = RNEW(J) * .0003048                                         PSVL1490
      WRITE (6,9005) T1,RNEW,RNM,VKM                                      PSVL1500    45
 9005 FORMAT (// 14H TIME (SEC) =  E17.8  /  12H R (FEET) =   3E17.8      PSVL1510
     1  /  12H R (KM  ) =   3E17.8    /  12H V (KPS)  =    3E17.8)        PSVL1520
C                                                                         PSVL1530
C                                                                         PSVL1540
C                                                                         PSVL1550
      MONK    = 2                                                         PSVL1560
C                                                                         PSVL1570
      RETURN                                                              PSVL1580
      END                                                                 PSVL1590
```

STORAGE MAP

SUBROUTINE POSVEL

COMMON VARIABLES

COMMON BLOCK ASTRO ORIGIN 00001 LENGTH 00004

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
GCON	00000	R	AJ	00001	R	RE	00002	R
RP	00003	R						

DIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
RNM	00005	R	VKM	00010	R			

UNDIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
MSUM	00013	R	NSUM	00014	R	MOR	00015	R
NOR	00016	R	MU	00017	R	NU	00020	R
NMOT	00021	R	MMU	00022	R	NNU	00023	R
DELT	00024	R	ASUM	00025	R	PSUM	00026	R
QSUM	00027	R	TSUM	00030	R	A	00031	R
P	00032	R	Q	00033	R	TCAP	00034	R
SGN	00035	R	THETAO	00036	R	AOR	00037	R
POR	00040	R	QOR	00041	R	TOR	00042	R
THETA	00043	R	DTHET	00044	R	THOPI	00045	R
PERIOD	00046	R	NREV1	00047	I	NREV2	00050	I
DA	00051	R	DP	00052	R	DQ	00053	R
DM	00054	R	DN	00055	R	DT	00056	R
DDA	00057	R	DDP	00060	R	DDQ	00061	R
DDM	00062	R	DDN	00063	R	DDT	00064	R
TEST	00065	R						

```
**** POSVL                          STORAGE  MAP              01/11/86          PAGE  7

                                    ENTRY POINTS

     POSVEL      SECTION     5

                                 SUBROUTINES CALLED

     OSCUL       SECTION     6     .FWRD.     SECTION    7      THET      SECTION     8
     DOBL        SECTION     9     DRAG       SECTION   10      SQRT      SECTION    11
     VECT        SECTION    12     .FSLO.     SECTION   13      .UN06.    SECTION    14
     .FFIL.      SECTION    15     .FCNV.     SECTION   16      CC.1      SECTION    17
     CC.2        SECTION    18     CC.3       SECTION   19      CC.4      SECTION    20
     SYSLOC      SECTION    21

                              EFN   IFN   CORRESPONDENCE

EFN        IFN       LOCATION    EFN       IFN       LOCATION   EFN       IFN      LOCATION
60          8A        00233      9001      FORMAT     00100     70        10A       00245
75         12A        00257      80         14A       00265     85        16A       00271
100        17A        00304      105        2CA       00320     110       22A       00324
290        28A        00461      300        33A       00500     9009      41A       00520
9005      FORMAT      00112
  DECK LENGTH IN OCTAL IS     00634.
```

Subroutine ØSCUL

Purpose: This routine computes the osculating elements corresponding to a given position vector, velocity vector and time.

Deck Name: ØSCULL

Calling Sequence: CALL ØSCUL (RVEC, RDØT, T, A, MU, NU, P, Q, TCAP, SGN, THETA)

Subroutines Called: CRØSS

Functions Called:
AMAG (vector magnitude)
DØT (dot product)
SQRT
ATAN2 (arc tangent)
SIN
CØS

Deck Length: 524_8

Input/Output:

I/O	FØRTRAN Name	Math Name	Dimension	Common/ Argument	Definition
I	RVEC	$\vec{R}$	3	Arg	position vector at time t
I	RDØT	$\dot{\vec{R}}$	3	Arg	velocity vector at time t
I	T	t	1	Arg	current time
Ø	A	a	1	Arg	semi-major axis
Ø	MU	μ	1	Arg	$\mu = e \sin \tilde{\omega}$
Ø	NU	ν	1	Arg	$\nu = e \cos \tilde{\omega}$
Ø	P	p	1	Arg	$p = \sin i \sin \Omega$
Ø	Q	q	1	Arg	$q = \sin i \cos \Omega$

I/O	FØRTRAN Name	Math Name	Dimension	Common/ Argument	Definition
Ø	TCAP	$\tilde{T}$	1	Arg	$\tilde{T} = t - n(\tilde{\omega} + M)$ = "time of equinox passage".
Ø	SGN		1	Arg	= +1 for posigrade orbits = -1 for retrograde orbits
Ø	THETA	θ	1	Arg	$\theta = \tilde{\omega} + f$ = longitude in the orbit
I	GCØN	k	1	ASTRØ	gravitational constant of Earth (length^3/time^2)
I	AJ	J	1	ASTRØ	first term in Jeffrey's gravitational potential
I	RE	R_E	1	ASTRØ	equatorial radius of the Earth
I	RP	R_P	1	ASTRØ	polar radius of the Earth

SUBROUTINE OSCUL

enter

$$r = |\vec{R}|$$

$$V = |\vec{V}|$$

$$\vec{H} = \vec{R} \times \vec{V}$$

$$h = |\vec{H}|$$

$$a = k_E r / (2 k_E - r V^2)$$

$$p = \frac{h_1}{h}$$

$$q = \frac{h_2}{h}$$

$$e \cos f = \frac{h^2}{k_E r} - 1$$

$$e \sin f = \frac{h}{k_E r} (\vec{R} \circ \dot{\vec{R}})$$

$$\left.\begin{aligned} A &= \frac{q}{1 \pm \sqrt{1 - p^2 - q^2}} \\ B &= \frac{p}{1 \pm \sqrt{1 - p^2 - q^2}} \end{aligned}\right\} \quad \text{use } + \text{ if } 0 \le i \le 90; \quad - \text{ if } 90 < i \le 180$$

$$\sin \theta = \frac{r_2 + A r_3}{r}$$

$$\cos \theta = \frac{r_1 - B r_3}{r}$$

$$\theta = \text{Arctan} \left(\frac{\sin \theta}{\cos \theta} \right)$$

$$\mu = e \cos f \sin \theta - e \sin f \cos \theta$$

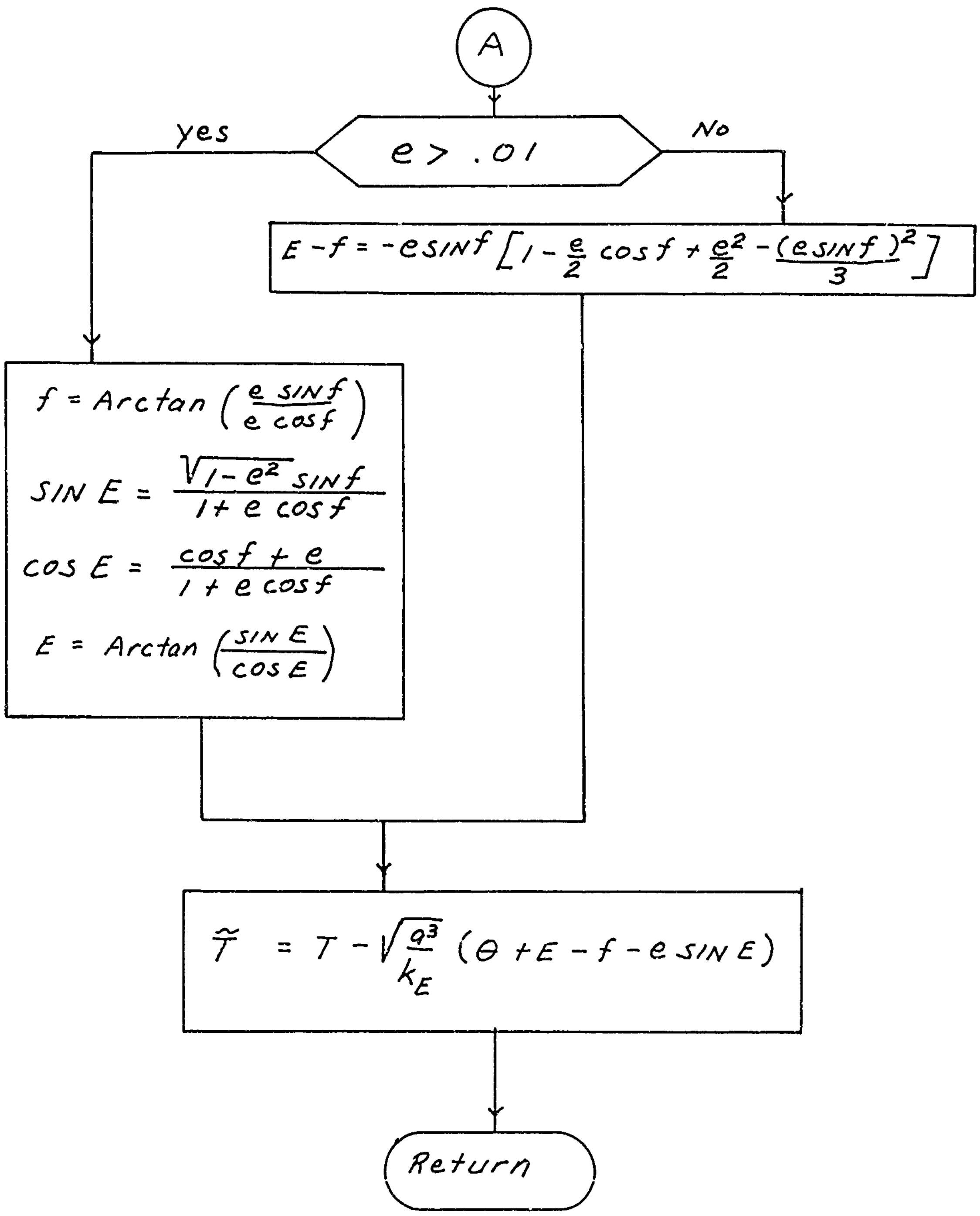
$$\nu = e \cos f \cos \theta + e \sin f \sin \theta$$

$$e = \sqrt{\mu^2 + \nu^2}$$

$$e \sin E = \frac{\sqrt{1 - e^2}\, e \sin f}{1 + e \cos f}$$

A

SUBROUTINE ØSCUL (cont.)



Description of Equations:

Subroutine ØSCUL computes the six osculating elements corresponding to a given position vector, velocity vector and time.

The semi-major axis, a, is computed first.

Let

$$r = |\vec{R}|$$

$$V = |\dot{\vec{R}}|$$

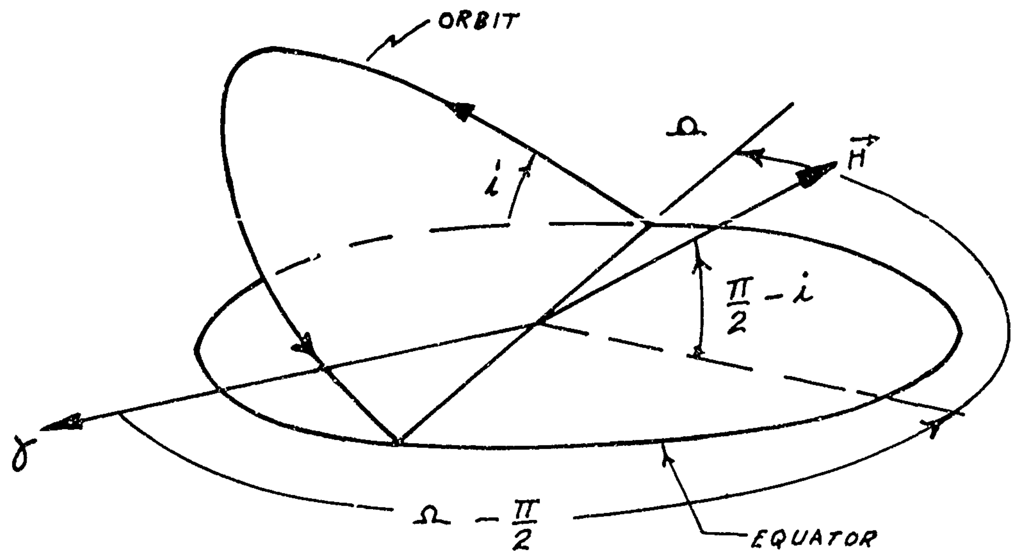
The energy equation is

$$\frac{-k}{a} = V^2 - \frac{2k}{r}$$

where k is the gravitational constant of the central body (length^3/time^2). It follows that

$$a = \frac{rk}{2k - rV^2} \tag{1}$$

The second and third elements, $p = \sin i \sin \Omega$ and $q = \sin i \cos \Omega$, are found from the angular momentum vector, $\vec{H}$. The sketch shows that the right ascension, α, and declination, δ, of $\vec{H}$



are

$$\alpha_H = \Omega - \frac{\pi}{2}$$

$$\delta_H = \frac{\pi}{2} - i$$

The vector, $\vec{H}$, can be written,

$$\vec{H} = (\cos\alpha_H \cos\delta_H , \sin\alpha_H \cos\delta_H , \sin\delta_H)$$

or

$$\vec{H} = (\sin i \sin\Omega , -\sin i \cos\Omega , \cos i)$$

In terms of p and q,

$$\vec{H} = (p, -q, \cos i)$$

Now, $\vec{H}$ can be computed directly from $\vec{R}$ and $\dot{\vec{R}}$

$$\vec{H} = \frac{\vec{R} \times \dot{\vec{R}}}{|\vec{R} \times \dot{\vec{R}}|} = (h_1, h_2, h_3)$$

and, finally

$$p = h_1$$

$$q = -h_2 \qquad (2)$$

The next two elements, $\mu = e\sin\tilde{\omega}$ and $\nu = e\cos\tilde{\omega}$, are computed using the variable $\theta = \tilde{\omega} + f$ = "longitude in the orbit" ($\tilde{\omega}$ = longitude of perifocus and f = true anomoly).
Write μ and ν as

$$\mu = e\sin\tilde{\omega} = e\sin(\theta - f)$$

$$= (e\cos f)\sin\theta - (e\sin f)\cos\theta$$

$$\nu = e\cos\tilde{\omega} = e\cos(\theta - f) \qquad (3)$$

$$= (e\cos f)\cos\theta + (e\sin f)\sin\theta$$

The four quantities $e \cos f$, $e \sin f$, $\sin \theta$, and $\cos \theta$ are determined below.

(1) $e \cos f$ can be found by combining the equation

$$r = \frac{a(1-e^2)}{1 + e\cos f} \tag{4}$$

with

$$h = |\vec{H}| = k a (1-e^2)$$

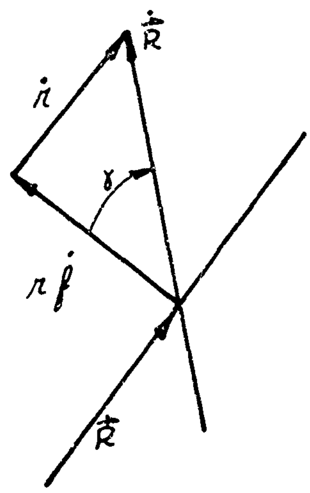
Thus

$$e \cos f = \frac{h^2}{kr} - 1 \tag{5}$$

(2) Differentiation of equation (4) yields

$$e \sin f = \frac{a(1-e^2)}{r^2} \frac{\dot{r}}{\dot{f}} \tag{6}$$

The sketch shows that $\dot{r}$ and $\dot{f}$ can be written



$$\dot{r} = \frac{(\vec{R} \cdot \dot{\vec{R}})}{r} \tag{7}$$

$$\dot{f} = \frac{V \cos \gamma}{r}$$

Using the expression for angular momentum

$$h = r V \cos \gamma$$

$\dot{f}$ becomes

$$\dot{f} = \frac{h}{r^2} \tag{8}$$

And substituting (7) and (8) into (6)

$$e \sin f = \frac{a(1-e^2)}{r^2} \frac{(\vec{R} \cdot \dot{\vec{R}})}{r} \frac{r^2}{h}$$

$$= \frac{a(1-e^2)}{rh} (\vec{R} \cdot \dot{\vec{R}}) \frac{h}{h}$$

$$= \frac{a(1-e^2)h(\vec{R} \cdot \dot{\vec{R}})}{rka(1-e^2)}$$

Thus

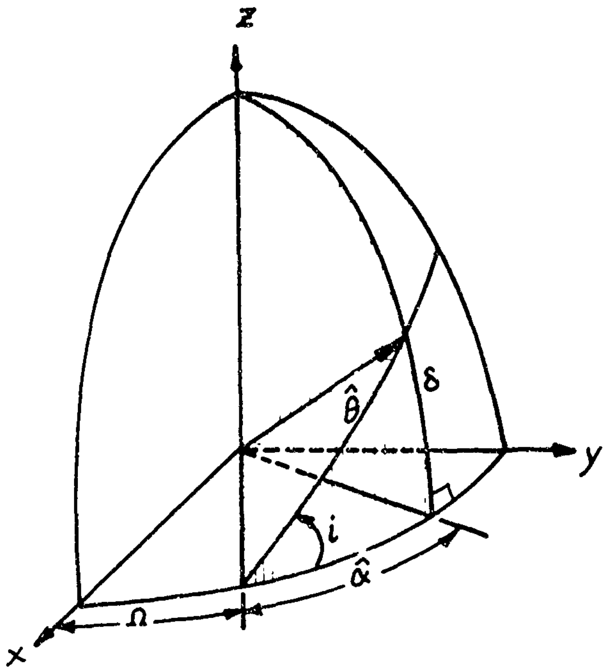
$$e \sin f = \frac{h}{rk} (\vec{R} \cdot \dot{\vec{R}}) \tag{9}$$

And the first two quantities are determined.

As an aid in finding $\sin\theta$ and $\cos\theta$ refer to the sketch below:

$$\theta = \tilde{\omega} + f = \Omega + \hat{\theta}$$

$$\alpha = \Omega + \hat{\alpha}$$



From spherical trigonometry,

$$\sin\hat{\theta}\sin i = \sin\delta$$

$$\cos i = \frac{\tan\hat{\alpha}}{\tan\hat{\theta}} = \frac{\sin\hat{\alpha}}{\cos\hat{\alpha}}\frac{\cos\hat{\theta}}{\sin\hat{\theta}}$$

$$\cos\hat{\theta} = \cos\hat{\alpha}\cos\delta$$

$$\sin\hat{\alpha} = \frac{\tan\delta}{\tan i} = \frac{\sin\delta}{\cos\delta}\frac{\cos i}{\sin i}$$

(3) Now, write $\sin\theta$

$$\sin\theta = \sin(\Omega + \hat{\theta}) = \sin\Omega\cos\hat{\theta} + \cos\Omega\sin\hat{\theta}$$

Substitute for $\hat{\theta}$

$$\sin\theta = \sin\Omega\cos\hat{\alpha}\cos\delta + \cos\Omega\frac{\sin\delta}{\sin i}$$

$$\sin\theta = \sin\Omega\cos\hat{\alpha}\cos\delta + \cos\Omega\sin\hat{\alpha}\cos\delta - \cos\Omega\sin\hat{\alpha}\cos\delta$$

$$+ \cos\Omega\frac{\sin\delta}{\sin i}$$

combine first two terms and substitute for $\hat{\alpha}$

$$\sin\theta = \cos\alpha - \cos\Omega\cos\delta\left[\frac{\sin\delta\cos i}{\cos\delta\sin i}\right] + \cos\Omega\frac{\sin\delta}{\sin i}$$

$$= \cos\delta\cos\alpha + \cos\Omega\sin\delta\left[\frac{1-\cos i}{\sin i}\right]$$

$$= \cos\delta\cos\alpha + \cos\Omega\sin\delta\frac{\sin i}{1+\cos i}$$

$$= \frac{r_1}{r} + \frac{r_3}{r}\left[\frac{q}{1+\cos i}\right] \tag{10}$$

(4) The same procedure yields

$$\cos\theta = \frac{r_1}{r} - \frac{r_3}{r}\left[\frac{p}{1+\cos i}\right] \tag{11}$$

The last osculating element, $\tilde{T}$, is

$$\tilde{T} = t - n(\tilde{\omega} + M)$$

where M = mean anomaly and $n = \sqrt{\frac{k}{a^3}}$, the mean motion.

Then, using Kepler's equation,

$$\tilde{T} = t - n(\tilde{\omega} + f - f + E - e\sin E)$$

$$= t - n\left[\theta + (E - f) - (e \sin E)\right] \tag{12}$$

The last term, $e \sin E$, is computed from

$$e \sin E = \frac{\sqrt{1-e^2}\,(e \sin f)}{1 + e \cos f}$$

where

$$\sqrt{1-e^2} = \sqrt{1-\mu^2-\nu^2}$$

and $e \sin f$ and $e \cos f$ are given by equations (5) and (9).

If $e = \sqrt{\mu^2+\nu^2}$ is small enough so that terms of order e^4 may be neglected $E-f$ can be computed from the series (see Reference, page 64)

$$E - f = -(e \sin f)\left[1 - \frac{1}{2}(e \cos f) + \frac{e^2}{2} - \frac{(e \sin f)^2}{3}\right]$$

If e is so large that the series cannot be used, f can be computed from $e \sin f$ and $e \cos f$

$$f = \text{Arctan}\left(\frac{e \sin f}{e \cos f}\right)$$

Then the eccentric anomaly, E, is computed from

$$\sin E = \frac{\sqrt{1-e^2}\,\sin f}{1 + e \cos f}$$

$$\cos E = \frac{e + \cos f}{1 + e \cos f}$$

And the difference, $E - f$, can be formed.

Reference: Brouwer, Dirk and Clemence, Gerald M., Methods of Celestial Mechanics, New York, Academic Press, 1961.

```
      SUBRØUTINE ØSCUL (RVEC,RDØT,T,A,MU,NU,P,Q,TCAP,SGN,THETA)         ØSCF0010
C                                                                        ØSC00020
C        THIS RØUTINE CØMPUTES A SET ØF 'LØW E, LØW I' ØSCULATING        ØSC00030
C        ELEMENTS FRØM A GIVEN PØSITIØN VELØCITY AND TIME.               ØSC00040
C        THE ØSCULATING ELEMENTS ARE  A, MU, NU, P, Q AND TCAP.          ØSC00050
C                                                                        ØSC00560
C        NØMENCLATURE                                                    ØSC00060
C           T        = CURRENT TIME                                      ØSC00070
C           RVEC     = PØSITIØN VECTØR AT TIME T.                        ØSC00080
C           RDØT     = VELØCITY VECTØR AT TIME T                         ØSC00090
C           HVEC     = ANGULAR MØMENTUM VECTØR                           ØSC00100
C           A        = SEMI MAJØR AXIS                                   ØSC00110
C           E        = ECCENTRICITY                                      ØSC00120
C           W        = LØNGITUDE ØF PERIGEE                              ØSC00130
C           MU       = E * SIN(W)                                        ØSC00140
C           NU       = E * CØS(W)                                        ØSC00150
C           INCL     = INCLINATIØN                                       ØSC00160
C           ØMEGA    = RIGHT ASCENSIØN ØF ASCENDING NØDE                 ØSC00170
C           P        = SIN(I) * SIN(ØMEGA)                               ØSC00180
C           Q        = SIN(I) * CØS(ØMEGA)                               ØSC00190
C           NMØT     = MEAN MØTIØN                                       ØSC00200
C           F        = TRUE ANØMØLY                                      ØSC00210
C           ECAP     = ECCENTRIC ANØMØLY                                 ØSC00220
C           THETA    = F + W  = 'LØNGITUDE IN THE ØRBIT'                 ØSC00230
C           TCAP     ='TIME ØF EQUINØX PASSAGE'                          ØSC00240
C           GCØN     = GRAVITATIØNAL CØNSTANT ØF THE EARTH.              ØSC00250
C                                                                        ØSC00260
      REAL MU, NU, INCL, NMØT                                            ØSC00270
      DIMENSIØN RVEC(3), RDØT(3), HVEC(3)                                ØSC00280
      CØMMØN /ASTRØ/ GCØN, AJ, RE, RP                                    ØSC00290
C                                                                        ØSC00300
      RR     = AMAG(RVEC)                                                ØSC00310   2
      VV     = AMAG(RDØT)                                                ØSC00320   3
      CALL CRØSS (RVEC, RDØT, HVEC)                                      ØSC00330   4
      HH     = AMAG(HVEC)                                                ØSC00340   6
      A      = GCØN*RR / (2.*GCØN - RR*VV**2)                            ØSC00350
```

```
     ØSCULL      -  EFN   SØURCE STATEMENT  -  IFN(S)  -

      P     = HVEC(1) / HH                                              ØSC00360
      Q     =-HVEC(2) / HH                                              ØSC00370
      ECØSF = HH**2 / (GCØN*RR) - 1.                                    ØSC00380
      ESINF = HH / (GCØN*RR) * DØT(RVEC,RDØT)                           ØSC00390   7
      CØSI  = SQRT (1. - P**2 - Q**2)                                   ØSC00400   8
      SGN   = HVEC(3) / ABS(HVEC(3))                                    ØSC00410
      DENØM = 1. + SGN*CØSI                                             ØSC00420
      AA    = Q / DENØM                                                 ØSC00430
      BB    = P / DENØM                                                 ØSC00440
      ST    = (RVEC(2) + AA*RVEC(3)) / RR                               ØSC00450
      CT    = (RVEC(1) - BB*RVEC(3)) / RR                               ØSC00460
      THETA = ATAN2 (ST,CT)                                             ØSC00470   9
      IF (THETA .LT. 0.) THETA = THETA + 6.2831853
      MU    = ECØSF*ST - ESINF*CT                                       ØSC00480
      NU    = ECØSF*CT + ESINF*ST                                       ØSC00490
      E     = SQRT (MU**2 + NU**2)                                      ØSC00500  12
      BRM   = SQRT (1. - E**2)                                          ØSC00640  13
      ESINE = BRM * ESINF / (1. + ECØSF)                                ØSC00650
      YØK   = SQRT (A**3 / GCØN)                                        ØSC00660
C                                                                       ØSC00510  14
      IF (E .GT. .01)  GØ TØ 400                                        ØSC00520
C                                                                       ØSC00530
      ELESF  = -ESINF * (1. - .5*ECØSF  + .5*E*E - .33333333*ESINF**2)  ØSC00540
      GØ TØ 460                                                         ØSC00550
C                                                                       ØSC00570
  400 F     = ATAN2 (ESINF,ECØSF)                                       ØSC00580  20
      DEN   = 1. + ECØSF                                                ØSC00590
      SINE  = BRM * SIN(F) / DEN                                        ØSC00600  21
      CØSE  = (CØS(F) + E) / DEN                                        ØSC00610  22
      ECAP  = ATAN2 (SINE , CØSE)                                       ØSC00620  23
      ELESF = ECAP - F                                                  ØSC00630
  460 TCAP  = T - YØK*(THETA + ELESF - ESINE)                           ØSC00670
C                                                                       ØSC00680
      RETURN                                                            ØSC00690
      END                                                               ØSC00700
```

SID 65-1203-3

ØSCULL STØRAGE MAP

SUBRØUTINE ØSCUL

COMMON VARIABLES

CØMMØN BLØCK ASTRØ ØRIGIN 00001 LENGTH 00004

SYMBØL	LØCATIØN	TYPE	SYMBØL	LØCATIØN	TYPE	SYMBØL	LØCATIØN	TYPE
GCØN	00000	R	AJ	00001	R	RE	00002	R
RP	00003	R						

DIMENSIØNED PRØGRAM VARIABLES

SYMBØL	LØCATIØN	TYPE	SYMBØL	LØCATIØN	TYPE	SYMBØL	LØCATIØN	TYPE
HVEC	00005	R						

UNDIMENSIØNED PRØGRAM VARIABLES

SYMBØL	LØCATIØN	TYPE	SYMBØL	LØCATIØN	TYPE	SYMBØL	LØCATIØN	TYPE
INCL	00010	R	NMØT	00011	R	RR	00012	R
VV	00013	R	HH	00014	R	ECØSF	00015	R
ESINF	00016	R	CØSI	00017	R	DENØM	00020	R
AA	00021	R	BB	00022	R	ST	00023	R
CT	00024	R	E	00025	R	BRM	00026	R
ESINE	00027	R	YØK	00030	R	ELESF	00031	R
F	00032	R	DEN	00033	R	SINE	00034	R
CØSE	00035	R	ECAP	00036	R			

ENTRY PØINTS

ØSCUL SECTIØN 5

SUBRØUTINES CALLED

STORAGE MAP

AMAG	SECTION	6	CROSS	SECTION	7	DOT	SECTION	8
SQRT	SECTION	9	ATAN2	SECTION	10	SIN	SECTION	11
COS	SECTION	12	SYSLOC	SECTION	13			

EFN IFN CORRESPONDENCE

EFN	IFN	LOCATION	EFN	IFN	LOCATION	EFN	IFN	LOCATION
400	19A	00363	460	24A	00424			

DECK LENGTH IN OCTAL IS 00532.

Subroutine THET

Purpose: This routine computes $\theta = \ell + \tilde{\omega}$ = longitude in the orbit, for a given time and set of orbital elements.

Deck Name: THETT

Calling Sequence: CALL THET (A, MU, NU, THETA, TCAP, TI, NMØT)

Subroutines Called: NØNE

Functions Called: SQRT
CØS
SIN
ATAN2 (arctangent)

Deck Length: 477_8

Input/Output:

I/O	FØRTRAN Name	Math Name	Dimension	Common/ Argument	Definition
I	A	a	1	Arg	semi-major axis
I	MU	μ	1	Arg	$e \sin \tilde{\omega}$
I	NU	ν	1	Arg	$e \cos \tilde{\omega}$
Ø	THETA	θ	1	Arg	$\ell + \tilde{\omega}$ = longitude in the orbit
I	TCAP	$\tilde{T}$	1	Arg	"time of equinox passage"
I	T1	t	1	Arg	current time
Ø	NMØT	n	1	Arg	mean motion = $\sqrt{\bar{k}/a^3}$
I	GCØN	$\bar{k}$	1	ASTRØ	gravitational constant of Earth = (length^3/time^2)

Development of Equations:

Subroutine THET computes the "longitude in the orbit", $\theta = f + \tilde{\omega}$, given time and a particular set of orbital elements. The mean motion and eccentricity will be needed

$$n = \sqrt{\frac{k}{a^3}}$$

$$e = \sqrt{\mu^2 + \nu^2}$$

If e is so small that terms of order e^4 can be neglected, θ is computed using a series expansion. First, let $\tilde{\alpha} = n(t - \tilde{T})$, $\tilde{s} = e \sin M$ and $\tilde{c} = e \cos M$.
Write $\tilde{s}$ as

$$\tilde{s} = e \sin M = e \sin (nt - nT)$$

$$= e \sin (nt - nT + \tilde{\omega} - \tilde{\omega})$$

$$= e \sin \left[nt - n\left(T - \frac{\tilde{\omega}}{n}\right) - \tilde{\omega}\right]$$

using $\tilde{T} = T - \dfrac{\tilde{\omega}}{n}$

$$\tilde{s} = e \sin \left[nt - n\tilde{T} - \tilde{\omega}\right] = e \sin (\tilde{\alpha} - \tilde{\omega})$$

$$= e \sin \tilde{\alpha} \cos \tilde{\omega} - e \cos \tilde{\alpha} \sin \tilde{\omega}$$

Finally

$$\tilde{s} = \nu \sin \tilde{\alpha} - \mu \cos \tilde{\alpha}$$

A similar manipulation shows that

$$\tilde{c} = \nu \cos\tilde{\alpha} + \mu \sin\tilde{\alpha}$$

The series expansion for f in terms of M is, (Reference, page III-27)

$$f = M + 2e \sin M + \frac{5}{4} e^2 \sin 2M + \frac{e^3}{12}(13 \sin 3M - 3 \sin M) + \ldots$$

Substituting

$$\sin 2M = 2 \sin M \cos M$$

$$\sin 3M = 3 \sin M - 4 \sin^3 M$$

and combining terms

$$f = M + 2(e \sin M) + \frac{5}{2}(e \sin M)(e \cos M) -$$

$$- 3(e \sin M)(e \cos M)^2 - \frac{4}{3}(e \sin M)^3$$

adding $\tilde{\omega}$ to both sides and noting that $\tilde{\theta} = f + \omega$ and $\tilde{\alpha} = n(t - \tilde{T}) = M + \tilde{\omega}$ we have

$$\tilde{\theta} = \tilde{\alpha} + \tilde{s}\left[2 + \frac{5}{2}\tilde{c} + \frac{4}{3}\tilde{s}^2 - 3\tilde{c}^2\right]$$

For the case of larger e, θ is computed via classic celestial mechanics methods. $\tilde{\omega}$ and M are found immediately.

$$\tilde{\omega} = \operatorname{Arctan}\left(\frac{\mu}{\nu}\right)$$

$$M = n(t - \tilde{T}) - \tilde{\omega}$$

Then, the eccentric anomaly, E, can be found from Kepler's equation,

$$M = E - e \sin E$$

bv a Newton-Raphson iteration technique. E_0 , the first guess for E, is selected by truncating the series for E in terms of M

$$E = M + e \sin M + \frac{e^2}{2} \sin(2M)$$

The estimate is improved according to

$$E_{i+1} = E_i + \frac{M - E_i + e \sin E_i}{1 - e \cos E_i}$$

The value of true anomaly, f , is obtained from

$$\sin f = \frac{\sqrt{1-e^2} \sin E}{1 - e \cos E}$$

$$\cos f = \frac{\cos E - e}{1 - e \cos E}$$

Finally,

$$\theta = f + \tilde{\omega}$$

Reference: Jensen, J., Kraft, K. D., and Townsend, G. T., "Orbital Mechanics, Chapter III, <u>Orbital Flight Handbook</u>", NASA SP-33, Volume 1, part 1, dated 1963.

```
      SUBROUTINE THET(A,MU,NU,THETA,TCAP,T1,NMOT)                          THET0010
C                                                                          THET0020
C        THIS ROUTINE COMPUTES THETA = 'LONGITUDE IN THE ORBIT' AT TIME    THET0030
C        T1.                                                               THET0035
C                                                                          THET0040
      REAL NU, MU, NMOT                                                    THET0050
      COMMON /ASTRO/ GCON, AJ, RE, RP                                      THET0060
      DATA  LMAX,LCOUNT,EPS  /15, 1, .000 000 06/                          THET0070
C                                                                          THET0080
      E        = SQRT (MU**2 + NU**2)                                      THET0090    2
      NMOT     = SQRT (GCON/A**3)                                          THET0100
C                                                                          THET1020    3
      DT       = T1 - TCAP                                                 THET1020
      PERIOD   = 6.2831853 / NMOT                                          THET1020
      NREV     = DT / PERIOD                                               THET1020
      REV      = NREV                                                      THET1020
      DT       = DT - REV*PERIOD                                           THET1020
      XM       = NMOT*DT                                                   THET1020
C                                                                          THET1020
   60 IF (E .GT. .01)  GO TO  310                                          THET0110
C                                                                          THET0120
      AWIG     = XM                                                        THET0130
      CA       = COS(AWIG)                                                 THET0140    8
      SA       = SIN(AWIG)                                                 THET0150    9
      SWIG     = NU*SA - MU*CA                                             THET0160
      CWIG     = NU*CA + MU*SA                                             THET0170
      THETA    = AWIG + SWIG * (2. + 2.5*CWIG - 1.3333333*SWIG**2          THET0180
     1             + 3.*CWIG**2)                                           THET0190
      GO TO 500                                                            THET0200
C                                                                          THET0210
C        SOLVE KEPLERS EQUATION ITERATIVELY IN CASE E .GT. .01.            THET0220
C        A NEWTON RAPHSON TECHNIQUE IS USED.                               THET0230
C                                                                          THET0240
  310 WWIG     = ATAN2 (MU,NU)                                             THET0250    12
      XMW      = XM - WWIG                                                 THET0280
      ECAP     = XMW + E*SIN(XMW) + E*E/2.*SIN(2.*XMW)                     THET0290    13    14
```

```
   70 XMOFE  = ECAP - E*SIN(ECAP)                                      THET0310    16
      TEST   = XMW - XMOFE                                             THET0320
      IF (ABS(TEST) .LT. EPS) GO TO 90                                 THET0330
      IF (LCOUNT .GT. LMAX) GO TO 80                                   THET0340
      LCOUNT = LCOUNT + 1                                              THET0350
      ECAP   = ECAP + TEST/(1. - E*COS(ECAP))                          THET0360    24
      GO TO 70                                                         THET0370
C                                                                      THET0380
   80 WRITE (6,82) XMW, XMOFE                                          THET0390    26
   82 FORMAT (// 39H ITERATION ON KEPLER'S EQUATION FAILED             THET0400
     1 / 16H MEAN ANOMOLY =  E17.8        16H LAST GUESS    =  E17.8)  THET0405
C                                                                      THET0410
   90 CE     = COS(ECAP)                                               THET0420    28
      SE     = SIN(ECAP)                                               THET0430    29
      DEN    = 1. - E*CE                                               THET0440
      E2RT   = SQRT (1. - E*E)                                         THET0450    30
      SF     = E2RT * SE / DEN                                         THET0460
      CF     = (CE-E) / DEN                                            THET0470
      F      = ATAN2 (SF,CF)                                           THET0480    31
      THETA  = F + WWIG                                                THET0530
C                                                                      THET0540
  500 LCOUNT = 0                                                       THET0550
      RETURN                                                           THET0560
      END                                                              THET0570
```

SUBROUTINE THET

COMMON VARIABLES

COMMON BLOCK ASTRO ORIGIN 00001 LENGTH 00004

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
GCGN	00000	R	AJ	00001	R	RE	00002	R
RP	00003	R						

UNDIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
E	00005	R	DT	00006	R	PERIOD	00007	R
NREV	00010	I	REV	00011	R	XM	00012	R
AWIG	00013	R	CA	00014	R	SA	00015	R
SWIG	00016	R	CWIG	00017	R	WWIG	00020	R
XMW	00021	R	ECAP	00022	R	XMOFE	00023	R
TEST	00024	R	EPS	00025	R	LCOUNT	00026	I
LMAX	00027	I	CE	00030	R	SE	00031	R
DEN	00032	R	E2RT	00033	R	SF	00034	R
CF	00035	R	F	00036	R			

ENTRY POINTS

THET SECTION 5

SUBROUTINES CALLED

SQRT	SECTION	6	COS	SECTION	7	SIN	SECTION	8
ATAN2	SECTION	9	.FWRD.	SECTION	10	.UN06.	SECTION	11
.FFIL.	SECTION	12	.FCNV.	SECTION	13	E.1	SECTION	14
E.2	SECTION	15	E.3	SECTION	16	E.4	SECTION	17

THETT STORAGE MAP

CC.1	SECTION	18	CC.2	SECTION	19	CC.3	SECTION	20
CC.4	SECTION	21	SYSLOC	SECTION	22			

EFN IFN CORRESPONDENCE

EFN	IFN	LOCATION	EFN	IFN	LOCATION	EFN	IFN	LOCATION
60	5A	00174	310	11A	00257	500	32A	00454
70	15A	00317	90	27A	00402	80	26A	00370
82	FORMAT	00061						

DECK LENGTH IN OCTAL IS 00521.

Subroutine DØBL

Purpose: To compute the perturbations of the nonsingular osculating elements due to oblateness

Deck Name: DØBØL

Calling Sequence: DØBL (A, P, Q, MU, NU, TCAP, TØ, TI, THETAØ, THETA, DA, DP, DQ, DM, DN, DT, NMØT)

Subroutines Called: ØBCØN

Functions Called: SIN
CØS
SQRT

Deck Length: 01750_8

Input/Output:

I/O	FØRTRAN Name	Math Name	Dimension	Common/ Argument	Definition
I	A	a	1	Arg	semi-major axis
I	P	p	1	Arg	$p = \sin i \sin \Omega$
I	Q	q	1	Arg	$q = \sin i \cos \Omega$
I	MU	μ	1	Arg	$\mu = e \sin \tilde{\omega}$
I	NU	ν	1	Arg	$\nu = e \cos \tilde{\omega}$
I	TCAP	$\tilde{T}$	1	Arg	"time of equinox passage"
I	TØ	t_0	1	Arg	current time
I	TI	t_1	1	Arg	time of prediction
I	THETAØ	θ_0	1	Arg	current longitude in the orbit
I	THETA	θ	1	Arg	longitude in the orbit at time of prediction

I/O	FØRTRAN Name	Math Name	Dimension	Common/ Argument	Definition
Ø	DA	Δa	1	Arg	change in semi-major axis
Ø	DP	Δp	1	Arg	change in p
Ø	DQ	Δq	1	Arg	change in q
Ø	DM	$\Delta \mu$	1	Arg	change in μ
Ø	DN	$\Delta \nu$	1	Arg	change in ν
Ø	DT	$\Delta \tilde{T}$	1	Arg	change in $\tilde{T}$
I	NMØT	n	1	Arg	mean motion
	GCØN	k_E	1	ASTRØ	gravitational constant of the earth
	AJ	J	1	ASTRØ	first harmonic in Jeffrey's gravitational potential
	RE	R_E	1	ASTRØ	equatorial radius of the earth

FLOW DIAGRAM DØBL

ENTER

$$\cos i = \sqrt{1-p^2-q^2}$$
$$e = \sqrt{\mu^2+\nu^2}$$
$$F_a = \frac{2JR_E^2}{a(1-e^2)^3}$$
$$F_p = \frac{JR^2}{[a(1-e^2)]^2}$$
$$F_q = F_p$$
$$F_\mu = F_p$$
$$F_\nu = F_p$$
$$F_{T_1} = \frac{F_p}{1-e^2}$$
$$F_{T_2} = \frac{F_p}{n}$$

CALL ØBCØN

$$\Delta a = \frac{2JR^2}{a^2(1-e^2)^3}\left\{(1+\mu\sin\theta+\nu\cos\theta)^3\left[\frac{1}{3}-(q\sin\theta-p\cos\theta)^2\right]\right\}_{\theta_0}^{\theta_1}$$

$$\Delta p = F_p\left\{P_1\theta+P_2\sin\theta+P_3\cos\theta+\frac{P_4}{2}\sin 2\theta+\frac{P_5}{2}\cos 2\theta+\frac{P_6}{6}\sin 3\theta+\frac{P_7}{6}\cos 3\theta\right\}_{\theta_0}^{\theta_1}$$

$$\Delta q = F_q\left\{q_1\theta_1+q_2\sin\theta+q_3\cos\theta+\frac{q_4}{2}\sin 2\theta+\frac{q_5}{2}\cos 2\theta+\frac{q_6}{6}\sin 3\theta+\frac{q_7}{6}\cos 3\theta\right\}_{\theta_0}^{\theta_1}$$

$$\Delta\mu = F_M\Big\{\mu_1\theta+\mu_2\sin\theta+\mu_3\cos\theta+\frac{\mu_4}{2}\sin 2\theta+\frac{\mu_5}{2}\cos 2\theta+\mu_6\sin 3\theta$$
$$-\mu_7\cos 3\theta+\frac{3}{8}\mu_8\sin 4\theta-\frac{3}{8}\mu_9\cos 4\theta+\frac{1}{16}\mu_{10}\sin 5\theta-\frac{1}{8}\mu_{11}\cos 5\theta\Big\}_{\theta_0}^{\theta_1}$$

$$\Delta\nu = F_N\Big\{\nu_1\theta+\nu_2\sin\theta+\nu_3\cos\theta+\frac{\nu_4}{2}\sin 2\theta+\frac{\nu_5}{2}\cos 2\theta+\nu_6\sin 3\theta$$
$$+\nu_7\cos 3\theta+\frac{3}{8}\nu_8\sin 4\theta+\frac{3}{8}\nu_9\cos 4\theta+\frac{\nu_{10}}{8}\sin 5\theta+\frac{\nu_{11}}{16}\cos 5\theta\Big\}_{\theta_0}^{\theta_1}$$

$$\Delta T = \frac{3}{2}\frac{\Delta a}{a}(\tilde{T}-t) - F_{T_1}(t-t_o)\left[1+\mu\sin\theta_o + \nu\cos\theta_o\right]^3\left[1-3(q\sin\theta_o - p\cos\theta_o)^2\right]$$

$$-F_{T_2}\left\{\frac{\cos i}{1+\cos i}\left[\varepsilon 2_1\theta + \frac{\varepsilon 2_2}{2}\sin\theta + \frac{\varepsilon 2_3}{2}\cos\theta + \frac{\varepsilon 2_4}{2}\sin 2\theta + \varepsilon 2_5 \cos 2\theta\right.\right.$$

$$\left. + \frac{\varepsilon 2_6}{6}\sin 3\theta - \frac{\varepsilon 2_7}{6}\cos 3\theta\right]_{\theta_0}^{\theta_1} + \sqrt{1-e^2}\left[\varepsilon 3_1\theta + \varepsilon 3_2\sin\theta - \varepsilon 3_3\cos\theta\right.$$

$$\left. + \varepsilon 3_4 \sin 2\theta + \varepsilon 3_5\cos 2\theta + \frac{\varepsilon 3_6}{4}\sin 3\theta - \frac{\varepsilon 3_7}{4}\cos 3\theta\right]_{\theta_0}^{\theta_1}$$

$$+ \frac{1}{1+\sqrt{1-e^2}}\left[\varepsilon 4_1\theta + \nu\varepsilon 4_2\sin\theta - \mu\varepsilon 4_3\cos\theta + \varepsilon 4_4\sin 2\theta\right.$$

$$\left. + \varepsilon 4_5\cos 2\theta + \varepsilon 4_6\sin 3\theta + \varepsilon 4_7\cos 3\theta\right]_{\theta_0}^{\theta_1} + \left[\varepsilon 4_8\sin\theta + \varepsilon 4_9\cos\theta\right.$$

$$+ \varepsilon 4_{10}\sin 2\theta + \varepsilon 4_{11}\cos 2\theta + \varepsilon 4_{12}\sin 3\theta + \varepsilon 4_{13}\cos 3\theta + \varepsilon 4_{14}\sin 4\theta$$

$$\left.\left. + \varepsilon 4_{15}\cos 4\theta + \varepsilon 4_{16}\sin 5\theta + \varepsilon 4_{17}\cos 5\theta\right]_{\theta_0}^{\theta_1}\right\}$$

RETURN

Development of Equations:

The general perturbation expressions for the changes in the non-singular osculating elements due to the first order oblateness perturbation have been taken from a formulation due to Lubowe (Appendix I). The non-singular elements

a = semi-major axis

$p = \sin i \sin \Omega$

$q = \sin i \cos i$

$\mu = e \sin \tilde{\omega}$

$\nu = e \cos \tilde{\omega}$

$\tilde{T} = t - \frac{\tilde{\omega}}{n}$

have been chosen to eliminate low e and/or low i singularities in the perturbation expressions, and the formulation is first order in the sense that only terms of order J have been retained. Terms of order J^2, H and D have been dropped.

The development begins with Lagrange's Planetary Equations, which express the orbit of a body experiencing a perturbing force in terms of the deviations of the orbital elements from those describing the unperturbed orbit. These equations are six first-order differential equations with time as the independent variable. The independent variable is transformed from time to the angle theta = "true anomaly + longitude of perigee" in the unperturbed orbit. The six differential equations can then be integrated between θ_0 and θ_1 by holding the orbital elements constant over the interval of integration. The result is a first order approximation to the changes in the elements due to the perturbation considered.

```
      SUBROUTINE DOBL (A,P,Q,MU,NU,TCAP,TO,T1,THETAO,THETA,DA,DP,DQ,DM, DOBL0010
     1 DN,DT,NMOT)                                                       DOBL0020
C                                                                        DOBL0030
C        THIS ROUTINE COMPUTES THE CHANGE IN THE ORBITAL ELEMENTS DUE    DOBL0040
C        TO THE OBLATENESS PERTURBATION                                  DOBL0050
C                                                                        DOBL0060
C        NOMENCLATURE                                                    DOBL0070
C             A      = UNPERTURBED SEMI MAJOR AXIS                       DOBL0080
C             P      = UNPERTURBED  SIN(I)*SIN(OMEGA)                    DOBL0090
C             Q      = UNPERTURBED  SIN(I)*COS(OMEGA)                    DOBL0100
C             MU     = UNPERTURBED  E*SIN(W)                             DOBL0110
C             NU     = UNPERTURBED  E*COS(W)                             DOBL0120
C             TCAP   = UNPERTURBED 'TIME OF EQUINOX PASSAGE'             DOBL0130
C             TO     = ORIGINAL TIME                                     DOBL0140
C             T1     = TIME OF PREDICTION                                DOBL0150
C             THETAO= LONGITUDE IN THE ORBIT AT TIME TO                  DOBL0160
C             THETA  = LONGITUDE IN THE ORBIT AT TIME T1                 DOBL0170
C             DA     = CHANGE IN A DUETO OBLATENESS                      DOBL0180
C             DP     = CHANGE IN P DUE TO OBLATENESS                     DOBL0190
C             DQ     = CHANGE IN Q DUE TO OBLATENESS                     DOBL0200
C             DM     = CHANGE IN MU DUE TO OBLATENESS                    DOBL0210
C             DN     = CHANGE IN NU DUE TO OBLATENESS                    DOBL0220
C             DT     = CHANGE IN TCAP DUE TO OBLATENESS                  DOBL0230
C                                                                        DOBL0240
      REAL MU, NU, MMU, NNU, NMOT                                        DOBL0250
      COMMON /OCONST/ PP(7), QQ(7), MMU(11), NNU(11), EPS2(7), EPS3(7),  DOBL0260
     1               EPS4(17)                                            DOBL0270
      COMMON /ASTRO/ GCON, AJ, RE, RP                                    DOBL0280
C                                                                        DOBL0290
      STT    = SIN(THETA)                                                DOBL0310    2
      CTT    = COS(THETA)                                                DOBL0320    3
      STO    = SIN(THETAO)                                               DOBL0330    4
      CTO    = COS(THETAO)                                               DOBL0340    5
      S2TT   = SIN(2.*THETA) - SIN(2.*THETAO)                            DOBL0350    6     7
      C2TT   = COS(2.*THETA) - COS(2.*THETAO)                            DOBL0360    8     9
      S3TT   = SIN(3.*THETA) - SIN(3.*THETAO)                            DOBL0370    10    11
```

```
      C3TT   = CØS(3.*THETA) - CØS(3.*THETAO)               DØBL0380   12   13
      S4TT   = SIN(4.*THETA) - SIN(4.*THETAO)               DØBL0390   14   15
      C4TT   = CØS(4.*THETA) - CØS(4.*THETAO)               DØBL0400   16   17
      S5TT   = SIN(5.*THETA) - SIN(5.*THETAO)               DØBL0410   18   19
      C5TT   = CØS(5.*THETA) - CØS(5.*THETAO)               DØBL0420
C                                                           DØBL0430   20   21
      PPQQ   = 1. - 1.5*(P*P + Q*Q)                         DØBL0300
      CØSI   = SQRT (1. - P**2 - Q**2)                      DØBL0440   22
      E2     = MU*MU + NU*NU                                DØBL0450
      ERT    = SQRT (1.-E2)                                 DØBL0970   23
      FA     = 2.*AJ*RE*RE / (A*(1.-E2)**3)                 DØBL0460
      FP     = AJ*RE*RE /(A*(1.-E2))**2                     DØBL0470
      FQ     = FP                                           DØBL0480
      FM     = FP                                           DØBL0490
      FN     = FP                                           DØBL0500
      FT1    = FP/(1.-E2)                                   DØBL0510
      FT2    = FP/NMØT                                      DØBL0520
C                                                           DØBL0530
      CALL ØBCØN (P,Q,MU,NU)                                DØBL0540
C                                                           DØBL0590   24
      DA1    = FA * (1. + MU*STT + NU*CTT)**3               DØBL0600
     1         * (.33333333 - (Q*STT - P*CTT)**2)           DØBL0610
      DAO    = FA * (1. + MU*STO + NU*CTO)**3               DØBL0620
     1         * (.33333333 - (Q*STO - P*CTO)**2)           DØBL0630
      DA     = DA1 - DAO                                    DØBL0640
C                                                           NCN00080
      DP     = FP * ((THETA-THETAO)*PP(1) + (STT-STO)*PP(2) DØBL0650
     1         + (CTT-CTO)*PP(3) + .5*S2TT*PP(4) + .5*C2TT*PP(5)   DØBL0660
     2         + .16666666*S3TT*PP(6) + .16666666*C3TT*PP(7))      DØBL0670
C                                                           NCN00060
      DQ     = FQ * ((THETA-THETAO)*QQ(1) + (STT-STO)*QQ(2) DØBL0680
     1         + (CTT-CTO)*QQ(3) + .5*S2TT*QQ(4) + .5*C2TT*QQ(5)   DØBL0690
     2         + .16666666*S3TT*QQ(6) + .16666666*C3TT*QQ(7))      DØBL0700
C                                                           NCN00040
      DM     = FM * ((THETA-THETAO)*MMU(1) + (STT-STO)*MMU(2)      DØBL0710
     1         + (CTT-CTO)*MMU(3) + .5*S2TT*MMU(4) + .5*C2TT*MMU(5)  DØBL0720
     2         + S3TT*MMU(6) - C3TT*MMU(7) + .375*S4TT*MMU(8)      DØBL0730
```

```
 3        - .375*C4TT*MMU(9) + .0625*S5TT*MMU(10)                DØBL0740
 4        - .125*C5TT*MMU(11))                                   DØBL0750
C                                                                NCN00020
  DN     = FN * ((THETA-THETAO)*NNU(1) + (STT-STO)*NNU(2)        DØBL0760
 1        + (CTT-CTO)*NNU(3) + .5*S2TT*NNU(4) + .5*C2TT*NNU(5)   DØBL0770
 2        + S3TT*NNU(6) + C3TT*NNU(7) + .375*S4TT*NNU(8)         DØBL0780
 3        + .375*C4TT*NNU(9) + .125*S5TT*NNU(10)                 DØBL0790
 4        + .0625*C5TT*NNU(11))                                  DØBL0800
C                                                                MCN00060
  DTT    = 1.5*DA/A*(TCAP-T1)                                    DØBL0810
 1        - FT1*(T1-TO) * (1. +MU*STO + NU*CTO)**3               DØBL0820
 2        * (1. - 3.*(Q*STO - P*CTO)**2)                         DØBL0830
  EP2    = (THETA-THETAO)*EPS2(1) + .5*(STT-STO)*EPS2(2)         DØBL0840
 1        + .5*(CTT-CTO)*EPS2(3) + .5*S2TT*EPS2(4) + C2TT*EPS2(5) DØBL0850
 2        + .16666666*S3TT*EPS2(6) - .16666666*C3TT*EPS2(7)      DØBL0860
  EP3    = (THETA-THETAO)*EPS3(1) + (STT-STO)*EPS3(2)            DØBL0870
 1        - (CTT-CTO)*EPS3(3) + S2TT*EPS3(4) + C2TT*EPS3(5)      DØBL0880
 2        + .25*S3TT*EPS3(6) - .25*C3TT*EPS3(7)                  DØBL0890
  EP4S1  = (THETA-THETAO)*EPS4(1) + NU*(STT-STO)*EPS4(2)         DØBL0900
 1        - MU*(CTT-CTO)*EPS4(3) + S2TT*EPS4(4) + C2TT*EPS4(5)   DØBL0910
 2        + S3TT*EPS4(6) + C3TT*EPS4(7)                          DØBL0920
  EP4S2  =   (STT-STO)*EPS4(8) + (CTT-CTO)*EPS4(9)               DØBL0930
 4        + S2TT*EPS4(10) + C2TT*EPS4(11) + S3TT*EPS4(12)        DØBL0940
 5        + C3TT*EPS4(13) + S4TT*EPS4(14) + C4TT*EPS4(15)        DØBL0950
 6        + S5TT*EPS4(16) + C5TT*EPS4(17)                        DØBL0960
  EPP    = CØSI/(1.+CØSI)*EP2 + ERT*EP3                          DØBL0980
 1        + (PPQQ*EP4S1 + EP4S2) / (1.+ERT)                      DØBL0990
  DT     = DTT - FT2*EPP                                         DØBL1000
C                                                                DØBL1010
  RETURN                                                         DØBL1020
  END                                                            DØBL1030
```

STORAGE MAP

SUBROUTINE DOBL

COMMON VARIABLES

COMMON BLOCK OCONST ORIGIN 00001 LENGTH 00103

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
PP	00000	R	QQ	00007	R	MMU	00016	R
NNU	00031	R	EPS2	00044	R	EPS3	00053	R
EPS4	00062	R						

COMMON BLOCK ASTRO ORIGIN 00104 LENGTH 00004

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
GCON	00000	R	AJ	00001	R	RE	00002	R
RP	00003	R						

UNDIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
STT	00110	R	CTT	00111	R	STO	00112	R
CTO	00113	R	S2TT	00114	R	C2TT	00115	R
S3TT	00116	R	C3TT	00117	R	S4TT	00120	R
C4TT	00121	R	S5TT	00122	R	C5TT	00123	R
PPQQ	00124	R	COSI	00125	R	E2	00126	R
ERT	00127	R	FA	00130	R	FP	00131	R
FQ	00132	R	FM	00133	R	FN	00134	R
FT1	00135	R	FT2	00136	R	DA1	00137	R
DAO	00140	R	DTT	00141	R	EP2	00142	R
EP3	00143	R	EP4S1	00144	R	EP4S2	00145	R
EPP	00146	R						

ENTRY POINTS

DOBL SECTION 7

```
****
    DOBOL                                    STORAGE  MAP          01/18/86             PAGE  8

                                              SUBROUTINES CALLED

   SIN         SECTION     8         COS        SECTION     9         SQRT        SECTION     10
   OBCON       SECTION     11        SYSLOC     SECTION     12

                                         EFN   IFN   CORRESPONDENCE

 EFN         IFN          LOCATION    EFN         IFN         LOCATION    EFN         IFN         LOCATION
  D''K LENGTH IN OCTAL IS      01574.
```

Subroutine ØBCØN

Purpose: This routine computes the constants in the expressions for the oblateness perturbations

Deck Name: ØBCØNN

Calling Sequence: SUBRØUTINE ØBCØN (P, Q, MU, NU)

Subroutines Called: NØNE

Functions Called: SQRT

Deck Length: 03507_8

Input/Output:

I/O	FØRTRAN Name	Math Name	Dimension	Common/ Argument	Definition
I	P	p	1	Arg	$p = \sin i \sin \Omega$
I	Q	q	1	Arg	$q = \sin i \cos \Omega$
I	MU	μ	1	Arg	$\mu = e \sin \tilde{\omega}$
I	NU	ν	1	Arg	$\nu = e \cos \tilde{\omega}$
Ø	PP(I)	p_i	7	ØCØNST	constants used in computing Δp
Ø	QQ(I)	q_i	7	ØCØNST	Δq
Ø	MMU(I)	μ_i	11	ØCØNST	$\Delta \mu$
Ø	NNU(I)	ν_i	11	ØCØNST	$\Delta \nu$
Ø	EPS2(I)	$\varepsilon 2_i$	7	ØCØNST	$\Delta \tilde{\tau}$
Ø	EPS3(I)	$\varepsilon 3_i$	7	ØCØNST	$\Delta \tilde{\tau}$
Ø	EPS4(I)	$\varepsilon 4_i$	17	ØCØNST	$\Delta \tilde{\tau}$

FLOW DIAGRAM ØBCØN

ENTER

$$P_1 = -q\cos i$$

$$P_2 = \nu q\left(\tfrac{1}{2} - \cos i - p^2\right) + \tfrac{1}{2}\mu p\left(1 - p^2 + q^2\right) + \frac{q}{1+\cos i}\left[\tfrac{1}{2}\nu\left(p^2 - q^2\right) - \mu p q\right]$$

$$P_3 = \mu q\left(\tfrac{1}{2} + \cos i - p^2\right) - \tfrac{1}{2}\nu p\left(1 - p^2 + q^2\right) + \frac{q}{1+\cos i}\left[\tfrac{1}{2}\mu\left(p^2 - q^2\right) + \nu p q\right]$$

$$P_4 = q\left(1 - 2p^2\right) + \frac{q}{1+\cos i}\left(p^2 - q^2\right)$$

$$P_5 = -p\left(1 - p^2 + q^2\right) + \frac{2pq^2}{1+\cos i}$$

$$P_6 = \nu q\left(1 - 2p^2\right) - \mu p\left(1 - p^2 + q^2\right) + \frac{q}{1+\cos i}\left[\nu\left(p^2 - q^2\right) + 2\mu p q\right]$$

$$P_7 = -\mu q\left(1 - 2p^2\right) - \nu p\left(1 - p^2 + q^2\right) + \frac{q}{1+\cos i}\left[-\mu\left(p^2 - q^2\right) + 2\nu p q\right]$$

$$Q_1 = p\cos i$$

$$Q_2 = \nu p\left(\tfrac{1}{2} + \cos i - q^2\right) - \tfrac{1}{2}\mu q\left[1 + p^2 - q^2\right] - \frac{p}{1+\cos i}\left[\tfrac{1}{2}\nu\left(p^2 - q^2\right) - \mu p q\right]$$

$$Q_3 = \mu p\left(\tfrac{1}{2} - \cos i - q^2\right) + \tfrac{1}{2}\nu q\left(1 + p^2 - q^2\right) - \frac{p}{1+\cos i}\left[\tfrac{1}{2}\mu\left(p^2 - q^2\right) + \nu p q\right]$$

$$Q_4 = p\left(1 - 2q^2\right) - \frac{p}{1+\cos i}\left(p^2 - q^2\right)$$

$$Q_5 = q\left(1 + p^2 - q^2\right) - 2p^2\frac{q}{1+\cos i}$$

$$Q_6 = \mu q\left(1 + p^2 - q^2\right) + \nu p\left(1 - 2q^2\right) + \frac{p}{1+\cos i}\left[\nu\left(q^2 - p^2\right) - 2\mu p q\right]$$

$$Q_7 = \nu q\left(1 + p^2 - q^2\right) - \mu p\left(1 - 2q^2\right) - \frac{p}{1+\cos i}\left[\mu\left(q^2 - p^2\right) + 2\nu p q\right]$$

B

B

$$\mu_1 = \nu\left[2 - \frac{5}{2}(p^2+q^2) - \cos i\right]$$

$$\mu_2 = \frac{1}{4}(p^2-q^2)(1+3\mu^2-2\nu^2) + \frac{5}{2}pq\mu\nu + \left[1-\frac{3}{2}(p^2+q^2)\right]\left[1+\frac{1}{4}(\mu^2+\nu^2)\right]$$

$$+\nu^2\left[\frac{3}{2} - \frac{7}{4}(p^2+q^2) - \cos i\right] + \frac{1}{2}\nu\,\frac{\cos i}{1+\cos i}\left[2\mu pq - \nu(p^2-q^2)\right]$$

$$\mu_3 = \frac{1}{4}pq(2+5\mu^2-3\nu^2) - \mu\nu\left(\frac{3}{2} - \frac{3}{4}p^2 - \frac{11}{4}q^2 - \cos i\right)$$

$$-\frac{1}{2}\nu\,\frac{\cos i}{1+\cos i}\left[\mu(p^2-q^2) + 2\nu pq\right]$$

$$\mu_4 = -\nu(p^2-q^2)\left[\frac{5}{2} - \frac{1}{1+\cos i}\right] + 5\mu pq + \nu\left[1-\frac{3}{2}(p^2+q^2)\right]$$

$$\mu_5 = -\frac{5}{2}\mu(p^2-q^2) - 2\nu pq\left[\frac{5}{2} - \frac{1}{1+\cos i}\right] - \mu\left[1. - \frac{3}{2}(p^2+q^2)\right]$$

$$\mu_6 = -\frac{1}{48}(p^2-q^2)(28+17\mu^2+11\nu^2) + \frac{1}{12}(\nu^2-\mu^2)\left[1-\frac{3}{2}(p^2+q^2)\right]$$

$$+\frac{1}{4}\mu\nu pq - \frac{1}{6}\nu\,\frac{\cos i}{1+\cos i}\left[\nu(p^2-q^2) + 2\mu pq\right]$$

$$\mu_7 = \frac{1}{24}pq(28+17\mu^2+11\nu^2) + \frac{1}{6}\mu\nu\left[1-\frac{3}{2}(p^2+q^2)\right] + \frac{1}{8}\mu\nu(p^2-q^2)$$

$$+\frac{1}{6}\nu\left(\frac{\cos i}{1+\cos i}\right)\left[2\nu pq - \mu(p^2-q^2)\right]$$

$$\mu_8 = \nu(q^2-p^2) - 2\mu pq$$

$$\mu_9 = 2\nu pq - \mu(p^2-q^2)$$

$$\mu_{10} = (\mu^2-\nu^2)(p^2-q^2) - 4\mu\nu pq$$

$$\mu_{11} = pq(\nu^2-\mu^2) - \mu\nu(p^2-q^2)$$

C

C

$$V_1 = \mu\left[\cos i - 2 + \tfrac{5}{2}\,(p^2+q^2)\right]$$

$$V_2 = \tfrac{1}{4}\,pq\,(2 - 3\mu^2 + 5\nu^2) - \mu\nu\left(\tfrac{3}{2} - \tfrac{11}{4}p^2 - \tfrac{3}{4}q^2 - \cos i\right)$$

$$-\tfrac{1}{2}\mu\left(\frac{\cos i}{1+\cos i}\right)\left[2\mu pq - \nu(p^2-q^2)\right]$$

$$V_3 = -\tfrac{1}{4}(p^2-q^2)(1-2\mu^2+3\nu^2) + \tfrac{5}{2}\mu\nu pq + \left[1-\tfrac{3}{2}(p^2+q^2)\right]\left[1+\tfrac{1}{4}(\mu^2+\nu^2)\right]$$

$$+\mu^2\left[\tfrac{3}{2} - \tfrac{7}{4}(p^2+q^2) - \cos i\right] + \tfrac{1}{2}\mu\left(\frac{\cos i}{1+\cos i}\right)\left[\mu(p^2-q^2) + 2\nu pq\right]$$

$$V_4 = 5\nu pq + \mu(p^2-q^2)\left[\tfrac{5}{2} - \frac{1}{1+\cos i}\right] + \mu\left[1-\tfrac{3}{2}(p^2+q^2)\right]$$

$$V_5 = -\tfrac{5}{2}\nu(p^2-q^2) - 2\mu pq\left(\tfrac{5}{2} - \frac{1}{1+\cos i}\right) + \nu\left[1-\tfrac{3}{2}(p^2+q^2)\right]$$

$$V_6 = \frac{pq}{24}(28+11\mu^2+17\nu^2) - \tfrac{1}{6}\mu\nu\left[1-\tfrac{3}{2}(p^2+q^2)\right] - \tfrac{1}{8}\mu\nu(p^2-q^2)$$

$$+\tfrac{1}{6}\mu\left(\frac{\cos i}{1+\cos i}\right)\left[\nu(p^2-q^2) + 2\mu pq\right]$$

$$V_7 = -\tfrac{1}{48}(p^2-q^2)(28+11\mu^2+17\nu^2) + \tfrac{1}{12}(\nu^2-\mu^2)\left[1-\tfrac{3}{2}(p^2+q^2)\right]$$

$$-\tfrac{1}{4}\mu\nu pq + \tfrac{1}{6}\mu\left(\frac{\cos i}{1+\cos i}\right)\left[2\nu pq - \mu(p^2-q^2)\right]$$

$$V_8 = 2\nu pq - \mu(p^2-q^2)$$

$$V_9 = \nu(q^2-p^2) - 2\mu pq$$

$$V_{10} = pq(\nu^2-\mu^2) - \mu\nu(p^2-q^2)$$

$$V_{11} = -(\nu^2-\mu^2)(p^2-q^2) - 4\mu\nu pq$$

D

D

$$\varepsilon 2_1 = -p^2 - q^2$$

$$\varepsilon 2_2 = 2\mu p q - \nu(3p^2 + q^2)$$

$$\varepsilon 2_3 = \mu(p^2 + 3q^2) - 2\nu p q$$

$$\varepsilon 2_4 = q^2 - p^2$$

$$\varepsilon 2_5 = -pq$$

$$\varepsilon 2_6 = -\nu(p^2 - q^2) - 2\mu p q$$

$$\varepsilon 2_7 = 2\nu p q - \mu(p^2 - q^2)$$

$$\varepsilon 3_1 = 1 - \tfrac{3}{2}(p^2 + q^2)$$

$$\varepsilon 3_2 = \nu(1 - \tfrac{9}{4}p^2 - \tfrac{3}{4}q^2) + \tfrac{3}{2}\mu p q$$

$$\varepsilon 3_3 = \mu(1 - \tfrac{3}{4}p^2 - \tfrac{9}{4}q^2) + \tfrac{3}{2}\nu p q$$

$$\varepsilon 3_4 = -\tfrac{3}{4}(p^2 - q^2)$$

$$\varepsilon 3_5 = -\tfrac{3}{2}pq$$

$$\varepsilon 3_6 = -\nu(p^2 - q^2) - 2\mu p q$$

$$\varepsilon 3_7 = -\mu(p^2 - q^2) + 2\nu p q$$

$$\varepsilon 4_1 = \mu^2 + \nu^2$$

$$\varepsilon 4_2 = 1 + \tfrac{3}{4}(\mu^2 + \nu^2)$$

$$\varepsilon 4_3 = 1 + \tfrac{3}{4}(\mu^2 + \nu^2)$$

E

E

$$\varepsilon 4_4 = \frac{1}{2}(\nu^2-\mu^2$$

$$\varepsilon 4_5 = -\mu\nu$$

$$\varepsilon 4_6 = \frac{1}{12}\nu(\nu^2-3\mu^2)$$

$$\varepsilon 4_7 = \frac{1}{12}\mu(\mu^2-3\nu^2)$$

$$\varepsilon 4_8 = \frac{1}{4}\left[\nu(q^2-p^2)(\mu^2+2\nu^2-1)+\mu pq(3\mu^2+5\nu^2-2)\right]$$

$$\varepsilon 4_9 = \frac{1}{4}\left[\mu(q^2-p^2)(2\mu^2+\nu^2-1)-\nu pq(5\mu^2+3\nu^2-2)\right]$$

$$\varepsilon 4_{10} = \frac{3}{4}(\mu^2+\nu^2)(q^2-p^2)$$

$$\varepsilon 4_{11} = -\frac{3}{2}(\mu^2+\nu^2)pq$$

$$\varepsilon P = \frac{7}{12}+\frac{11}{48}(\mu^2+\nu^2)$$

$$\varepsilon 4_{12} = \varepsilon P\left[\nu(q^2-p^2)-2\mu pq\right]$$

$$\varepsilon 4_{13} = \varepsilon P\left[\mu(p^2-q^2)-2\nu pq\right]$$

$$\varepsilon 4_{14} = \frac{3}{8}\left[(\nu^2-\mu^2)(q^2-p^2)-4\mu\nu pq\right]$$

$$\varepsilon 4_{15} = -\frac{3}{4}\left[\mu\nu(q^2-p^2)+(\nu^2-\mu^2)pq\right]$$

$$\varepsilon 4_{16} = \frac{1}{16}\left[(\nu^2-3\mu^2)\nu(q^2-p^2)+2\mu(\mu^2-3\nu^2)pq\right]$$

$$\varepsilon 4_{17} = \frac{1}{16}\left[(\mu^2-3\nu^2)\mu(q^2-p^2)-2\nu(\nu^2-3\mu^2)pq\right]$$

RETURN

```
      SUBRØUTINE ØBCØN (P,Q,MU,NU)                                      ØBN00010
C                                                                       ØBN00020
      REAL MU, NU, MMU, NNU, MU2, NU2                                   ØBN00030
C                                                                       ØBN00040
C        THIS RØUTINE CØMPUTES THE CØNSTANTS USED IN THE ØBLATENESS    ØBN00050
C        PERTURBATIØN.                                                  ØBN00060
C                                                                       ØBN00070
      CØMMØN /ØCØNST/ PP(7), QQ(7), MMU(11), NNU(11), EPS2(7), EPS3(7), ØBN00080
     1                EPS4(17)                                          ØBN00090
C                                                                       ØBN00100
C        CØMPUTE CØNSTANTS                                              ØBN00110
C                                                                       ØBN00120
      PQ      = P*Q                                                     ØBN00130
      P2      = P*P                                                     ØBN00140
      Q2      = Q*Q                                                     ØBN00150
      MU2     = MU*MU                                                   ØBN00160
      NU2     = NU*NU                                                   ØBN00170
      P2Q2    = P2 - Q2                                                 ØBN00180
      Q2P2    = Q2 - P2                                                 ØBN00190
      P2PQ2   = P2 + Q2                                                 ØBN00200
      CØSI    = SQRT (1. - P*P - Q*Q)                                   ØBN00210
C                                                                       ØBN00220
C        CØMPUTE CØNSTANTS FØR P                                        ØBN00230
C                                                                       ØBN00240   2
      PP(1)   = -Q*CØSI                                                 ØBN00250
      PP(2)   = NU*Q * (.5 - CØSI - P*P) + .5*MU*P * (1. - P2Q2)        ØBN00260
     1          + Q / (1. + CØSI) * (.5*NU*P2Q2 - MU*PQ)                ØBN00270
      PP(3)   = MU*Q * (.5 + CØSI - P*P) - .5*NU*P * (1. - P2Q2)        ØBN00280
     1          + Q / (1. + CØSI) * (.5*MU*P2Q2 + NU*PQ)                ØBN00290
      PP(4)   = Q*(1. - 2.*P*P) + Q/(1. + CØSI)*P2Q2                    ØBN00300
      PP(5)   = -P*(1. - P2Q2) + 2.*P*Q*Q/(1. + CØSI)                   ØBN00310
      PP(6)   = NU*Q*(1. - 2.*P*P) - MU*P*(1. - P2Q2)                   ØBN00320
     1          + Q/(1. +CØSI)*(NU*P2Q2 + 2.*MU*PQ)                     ØBN00330
      PP(7)   = -MU*Q*(1. - 2.*P*P) - NU*P*(1. - P2Q2)                  ØBN00340
     1          + Q/(1. + CØSI)*(-MU*P2Q2 + 2.*NU*PQ)                   ØBN00350
                                                                        ØBN00360
```

```
C         CØMPUTE CØNSTANTS FØR Q                                     ØBN00370
C                                                                     ØBN00380
      QQ(1)  = P*CØSI                                                 ØBN00390
      QQ(2)  = NU*P*(.5 + CØSI - Q*Q) - .5*MU*Q*(1.+P2Q2)             ØBN00400
     1         - P/(1. + CØSI)*(.5*NU*P2Q2 - MU*PQ)                   ØBN00410
      QQ(3)  = MU*P*(.5 - CØSI - Q*Q) + .5*NU*Q*(1.+P2Q2)             ØBN00420
     1         - P/(1. + CØSI)*(.5*MU*P2Q2 + NU*PQ)                   ØBN00430
      QQ(4)  = P*(1. - 2.*Q*Q) - P/(1. + CØSI)*P2Q2                   ØBN00440
      QQ(5)  = Q*(1. + P2Q2) - 2.*P*P*Q/(1. + CØSI)                   ØBN00450
      QQ(6)  = MU*Q*(1. + P2Q2) + NU*P*(1. - 2.*Q*Q)                  ØBN00460
     1         + P/(1. + CØSI)*(NU*(-P2Q2) - 2.*MU*PQ)                ØBN00470
      QQ(7)  = NU*Q*(1. + P2Q2) - MU*P*(1. - 2.*Q*Q)                  ØBN00480
     1         - P/(1. + CØSI)*(MU*(-P2Q2) + 2.*NU*PQ)                ØBN00490
C                                                                     ØBN00500
C         CØMPUTE CØNSTANTS FØR MU                                    ØBN00510
C                                                                     ØBN00520
      MMU(1) = NU * (2. - 2.5*P2PQ2 - CØSI)                           ØBN00530
      MMU(2) = .25*P2Q2*(1. + 3.*MU*MU - 2.*NU*NU) + 2.5*PQ*MU*NU     ØBN00540
     1         + (1. - 1.5*P2PQ2) * (1. + .25*(MU*MU + NU*NU))        ØBN00550
     2         + NU*NU * (1.5 - 1.75*P2PQ2 - CØSI)                    ØBN00560
     3         + .5*NU*CØSI / (1. + CØSI) * (2.*MU*PQ - NU*P2Q2)      ØBN00570
      MMU(3) = .25*PQ*(2. + 5.*MU*MU - 3.*NU*NU)                      ØBN00580
     1         - MU*NU * (1.5 - .75*P*P - 2.75*Q*Q - CØSI)            ØBN00590
     2         - .5*NU*CØSI / (1. + CØSI) *(MU*P2Q2 + 2.*NU*PQ)       ØBN00600
      MMU(4) = -NU*P2Q2 * (2.5 - 1./(1. + CØSI))                      ØBN00610
     1         + 5.*MU*PQ + NU*(1. - 1.5*P2PQ2)                       ØBN00620
      MMU(5) = -2.5*MU*P2Q2 - 2.*NU*PQ * (2.5 - 1./(1. + CØSI))       ØBN00630
     1         - MU * (1. - 1.5*P2PQ2)                                ØBN00640
      MMU(6) = -.020833333*P2Q2 * (28. + 17.*MU*MU + 11.*NU*NU)       ØBN00650
     1         + .083333333*(NU*NU - MU*MU) * (1. - 1.5*P2PQ2)        ØBN00660
     2         + .25*MU*NU*PQ                                         ØBN00670
     3         - .16666666*NU*CØSI/(1.+CØSI)*(NU*P2Q2 + 2.*MU*PQ)     ØBN00680
      MMU(7) = .041666666*PQ * (28. + 17.*MU*MU + 11.*NU*NU)          ØBN00690
     1         + .16666666*NU*MU * (1. - 1.5*P2PQ2)                   ØBN00700
     2         + .125*MU*NU*P2Q2                                      ØBN00710
     3         + .16666666*NU*CØSI/(1.+CØSI) *(2.*NU*PQ - MU*P2Q2)    ØBN00720
      MMU(8) = -(NU*P2Q2 + 2.*MU*PQ)                                  ØBN00730
```

```
      MMU(9) =  2.*NU*PQ - MU*P2Q2                                     ØBN00740
      MMU(10) = (MU*MU - NU*NU)*P2Q2 - 4.*MU*NU*PQ                     ØBN00750
      MMU(11) = PQ*(NU*NU - MU*MU) - NU*MU*P2Q2                        ØBN00760
C                                                                      ØBN00770
C        CØMPUTE CØNSTANTS FØR NU                                      ØBN00780
C                                                                      ØBN00790
      NNU(1)  = MU * (CØSI - 2. + 2.5*P2PQ2)                           ØBN00800
      NNU(2)  = .25*PQ * (2. - 3.*MU*MU + 5.*NU*NU)                    ØBN00810
     1          - MU*NU * (1.5 - 2.75*P*P - .75*Q*Q - CØSI)            ØBN00820
     2          - .5*MU*CØSI / (1.+CØSI) * (2.*MU*PQ - NU*P2Q2)        ØBN00830
      NNU(3)  = -.25*P2Q2 * (1. - 2.*MU*MU + 3.*NU*NU) + 2.5*MU*NU*PQ  ØBN00840
     1          + (1. - 1.5*P2PQ2) * (1. + .25*(MU*MU + NU*NU))        ØBN00850
     2          + MU*MU * (1.5 - 1.75*P2PQ2 - CØSI)                    ØBN00860
     3          + .5*MU*CØSI/(1.+CØSI)  * (MU*P2Q2 + 2.*NU*PQ)         ØBN00870
      NNU(4)  = 5.*NU*PQ + MU*P2Q2 * (2.5 - 1./(1.+CØSI))              ØBN00880
     1          + MU * (1. - 1.5*P2PQ2)                                ØBN00890
      NNU(5)  = -2.5*NU*P2Q2 - 2.*MU*PQ * (2.5 - 1./(1.+CØSI))         ØBN00900
     1          + NU * (1. - 1.5*P2PQ2)                                ØBN00910
      NNU(6)  = .041666666*PQ * (28. + 11.*MU*MU + 17.*NU*NU)          ØBN00920
     1          - .16666666*NU*MU * (1. - 1.5*P2PQ2)                   ØBN00930
     2          - .125*MU*NU*P2Q2                                      ØBN00940
     3          + .16666666*MU*CØSI/(1.+CØSI) * (NU*P2Q2 + 2.*MU*PQ)   ØBN00950
      NNU(7)  = -.020888888*P2Q2 * (28. + 11.*MU*MU + 17.*NU*NU)       ØBN00960
     1          + .083333333*(NU*NU - MU*MU) * (1. - 1.5*P2PQ2)        ØBN00970
     2          - .25*NU*MU*PQ                                         ØBN00980
     3          + .16666666*MU*CØSI/(1.+CØSI) * (2.*NU*PQ - MU*P2Q2)   ØBN00990
      NNU(8)  = 2.*NU*PQ - MU*P2Q2                                     ØBN01000
      NNU(9)  = -(NU*P2Q2 + 2.*MU*PQ)                                  ØBN01010
      NNU(10) = PQ * (NU*NU - MU*MU) - MU*NU*P2Q2                      ØBN01020
      NNU(11) = -(NU*NU - MU*MU)*P2Q2 - 4.*MU*NU*PQ                    ØBN01030
C                                                                      ØBN01040
C        CØMPUTE CØNSTANTS FØR T                                       ØBN01050
C                                                                      ØBN01060
      EPS2(1)  = -P2PQ2                                                ØBN01070
      EPS2(2)  = 2.*MU*PQ - NU*(3.*P2 + Q2)                            ØBN01080
      EPS2(3)  = MU*(P2 + 3.*Q2) - 2.*NU*PQ                            ØBN01090
      EPS2(4)  = -P2Q2                                                 ØBN01100
```

```
      EPS2(5)  = -PQ                                                   ØBN01110
      EPS2(6)  = -NU*P2Q2 - 2.*MU*PQ                                   ØBN01120
      EPS2(7)  = 2.*NU*PQ - MU*P2Q2                                    ØBN01130
C                                                                      ØBN01140
      EPS3(1)  = 1. - 1.5*P2PQ2                                        ØBN01150
      EPS3(2)  = NU * (1. - 2.25*P2 - .75*Q2) + 1.5*MU*PQ              ØBN01160
      EPS3(3)  = MU * (1. - .75*P2 - 2.25*Q2) + 1.5*NU*PQ              ØBN01170
      EPS3(4)  = -.75*P2Q2                                             ØBN01180
      EPS3(5)  = -1.5*PQ                                               ØBN01190
      EPS3(6)  = -NU*P2Q2 - 2.*MU*PQ                                   ØBN01200
      EPS3(7)  = -MU*P2Q2 + 2.*NU*PQ                                   ØBN01210
C                                                                      ØBN01220
      EPS4(1)  = MU2 + NU2                                             ØBN01230
      EPS4(2)  = 1. + .75*(NU2 + MU2)                                  ØBN01240
      EPS4(3)  = EPS4(2)                                               ØBN01250
      EPS4(4)  = .5*(NU2 - MU2)                                        ØBN01260
      EPS4(5)  = -MU*NU                                                ØBN01270
      EPS4(6)  = .083333333*NU*(NU2 - 3.*MU2)                          ØBN01280
      EPS4(7)  = .083333333*MU*(MU2 - 3.*NU2)                          ØBN01290
      EPS4(8)  = .25 * (NU*Q2P2*(MU2 + 2.*NU2 - 1.)                    ØBN01300
     1           + MU*PQ*(3.*MU2 + 5.*NU2 - 2.))                       ØBN01310
      EPS4(9)  = .25 * (MU*Q2P2*(2.*MU2 + NU2 - 1.)                    ØBN01320
     1           - NU*PQ*(5.*MU2 + 3.*NU2 -2.))                        ØBN01330
      EPS4(10) = .75*(MU2 + NU2)*Q2P2                                  ØBN01340
      EPS4(11) = -1.5*(MU2 + NU2)*PQ                                   ØBN01350
      EPPP     = (.58333333 + .22916666*(MU2 + NU2))                   ØBN01360
      EPS4(12) = EPPP * (NU*Q2P2 - 2.*MU*PQ)                           ØBN01370
      EPS4(13) = EPPP * (MU*P2Q2 - 2.*NU*PQ)                           ØBN01380
      EPS4(14) = .375 *((NU2 - MU2)*Q2P2 - 4.*MU*NU*PQ)                ØBN01390
      EPS4(15) = -.75 * (MU*NU*Q2P2 + (NU2 - MU2)*PQ)                  ØBN01400
      EPS4(16) = .0625 * ((NU2 - 3.*MU2)*NU*Q2P2 + 2.*MU*(MU2 - 3.*NU2) ØBN01410
     1           * PQ)                                                 ØBN01420
      EPS4(17) = .0625 * ((MU2 - 3.*NU2)*MU*Q2P2 - 2.*NU*(NU2- 3.*MU2) ØBN01430
     1           * PQ)                                                 ØBN01440
C                                                                      ØBN01450
      RETURN                                                           ØBN01460
      END                                                              ØBN01470
```

SUBROUTINE OBCON

COMMON VARIABLES

COMMON BLOCK OCONST ORIGIN 00001 LENGTH 00103

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
PP	00000	R	QQ	00007	R	MMU	00016	R
NNU	00031	R	EPS2	00044	R	EPS3	00053	R
EPS4	00062	R						

UNDIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
MU2	00104	R	NU2	00105	R	PQ	00106	R
P2	00107	R	Q2	00110	R	P2Q2	00111	R
Q2P2	00112	R	P2PQ2	00113	R	COSI	00114	R
EPPP	00115	R						

ENTRY POINTS

OBCON SECTION 5

SUBROUTINES CALLED

SQRT SECTION 6 SYSLOC SECTION 7

EFN IFN CORRESPONDENCE

EFN	IFN	LOCATION	EFN	IFN	LOCATION	EFN	IFN	LOCATION

DECK LENGTH IN OCTAL IS 03506.

Subroutine DRAG

Purpose: To compute the changes in the nonsingular orbital elements due to drag over the time period $t_1 - t_0$.

Deck Name: DRAGG

Calling Sequence: SUBROUTINE DRAG (A, P, Q, MU, NU, DDA, DDP, DDQ, DDM, DDN, DDT, TØ, TI, AMØT, WCDA)

Subroutines Called: DENSIT

Functions Called: SIN
CØS
ATAN2 (Arctan)
SQRT
BESEL (Bessel Functions)

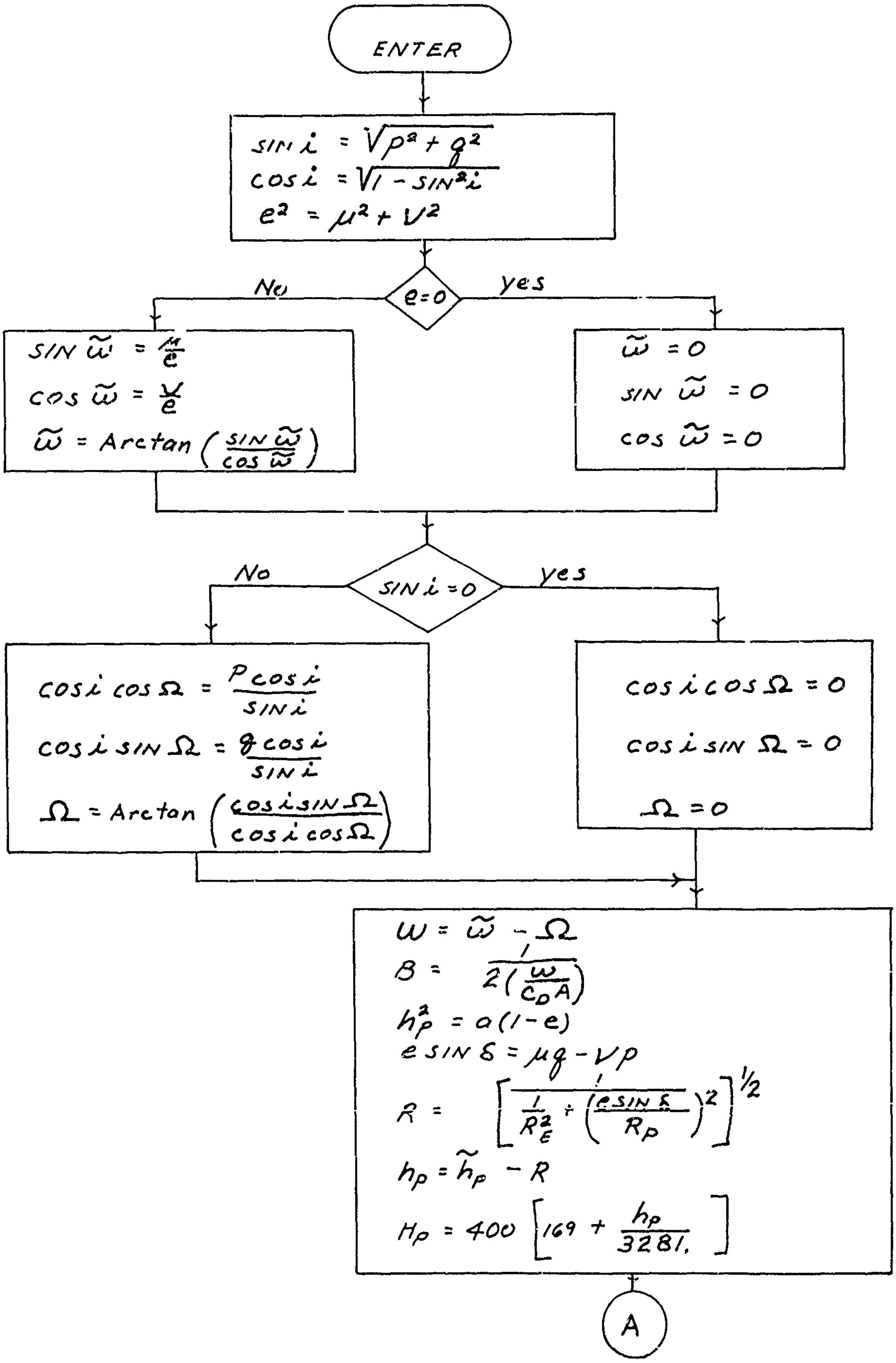
Deck Length: 01473_8

Input/Output:

I/O	FØRTRAN Name	Math Name	Dimension	Common/ Argument	Definition
I	A	a	1	Arg	a = semi-major axis
I	P	p	1	Arg	$p = \sin i \sin \Omega$
I	Q	q	1	Arg	$q = \sin i \cos \Omega$
I	MU	μ	1	Arg	$\mu = e \sin \tilde{\omega}$
I	NU	ν	1	Arg	$\nu = e \cos \tilde{\omega}$
Ø	DDA	δa	1	Arg	change in a
Ø	DDP	δp	1	Arg	change in p
Ø	DDQ	δq	1	Arg	change in q
Ø	DDM	$\delta \mu$	1	Arg	change in μ
Ø	DDN	$\delta \nu$	1	Arg	change in ν
Ø	DDT	$\delta \tilde{T}$	1	Arg	change in $\tilde{T}$

I/O	FØRTRAN Name	Math Name	Dimension	Common/ Argument	Definition
I	TØ	t_o	1	Arg	current time
I	TI	t_1	1	Arg	prediction time
I	AMØT	n	1	Arg	mean motion
I	WCDA	$\frac{W}{C_D A}$	1	Arg	$\frac{W}{C_D A}$ ~ pounds/square feet

SUBROUTINE DRAG



A

$$\rho_p = DENSIT\ (h_p)$$

$$F = 1 - 2\left(\frac{\omega_E}{n}\right)(1-e)\sqrt{\frac{1-e}{1+e}}\cos i$$

$$e = \frac{ae}{H_p}$$

$C < 2.$ — yes → C

NO

$$F^* = \frac{e}{1-e^2}\left[e + \frac{F-1}{\sqrt{F}}\right]$$

$$Q = 2B\rho_p a^2 F\,\frac{(1+e)^2}{\sqrt{1-e}}\sqrt{\frac{2\pi}{c}}$$

$$D = 2\pi B\left(\frac{\omega_E}{n}\right) a\rho_p\,\frac{\sqrt{F}}{\sqrt{2\pi c}}$$

$$\Delta a = -Q\left[1 + \frac{(1-8e+3e^2)}{8c(1-e^2)}\right]$$

$$\Delta e = -Q\left[\frac{1-e}{a}\right]\left[1 - \frac{3+4e-3e^2}{8c(1-e^2)}\right]$$

$$\Delta i = -D(1-e)^2\left\{\cos^2 w + \frac{1}{8c}\left[8\left(\frac{1+e}{1-e}\right) + 4F^* + \frac{(9e^2+6e-15)}{(1-e)^2}\right]\right\}\cos^2 w \sin i$$

$$\Delta\Omega = -D(1-e)^2\left\{1 + \frac{1}{8c}\left[4F^* + \frac{(9e^2+6e-15)}{(1-e)^2}\right]\right\}\cos w \sin i$$

$$\Delta w = -\cos i\ \Delta\Omega$$

B

C

$$K = \frac{\pi}{\left(\frac{w}{C_D A}\right)} \left(\frac{\omega_E}{n}\right) a \rho_p \sqrt{F}\, e^{-c}$$

$$G = \frac{2\pi}{\left(\frac{w}{C_D A}\right)} a^2 \rho_p F e^{-c}$$

$$\Delta a = -G(1+e)\sqrt{\frac{1+e}{1-e}}\left[(1-2e)\, I_0(c) + 2e\, I_1(c)\right]$$

$$\Delta e = -\frac{G}{a}\sqrt{\frac{1+e}{1-e}}\left[(1-e)\, I_1(c) + \frac{e}{2}(I_0(c) + I_2(c)\right]$$

$$\Delta i = -K\left\{\frac{1}{2}\left[(I_0(c) - I_2(c)\right] + \cos^2 w\left[I_2(c) - 2e\, I_1(c)\right]\right\} \sin i$$

$$\Delta \Omega = -K\left[I_2(c) - 2e\, I_1(c)\right] \sin w \cos w$$

$$\Delta w = -\cos i\, \Delta\Omega$$

B

$$\Delta \mu = \sin \tilde{\omega}\, \Delta e + \nu(\Delta\Omega + \Delta w)$$

$$\Delta \nu = \cos \tilde{\omega}\, \Delta e - \mu(\Delta\Omega + \Delta w)$$

$$\Delta p = \cos i \sin \Omega\, \Delta i + q\, \Delta\Omega$$

$$\Delta q = \cos i \cos \Omega\, \Delta i - p\, \Delta\Omega$$

$$\Delta \tilde{T} = \frac{-(\Delta W + \Delta\Omega}{n}$$

E

D

$$\chi = \frac{n \Delta t}{2\pi}$$

$$\delta a = \chi(\Delta a)$$

$$\delta p = \chi(\Delta p)$$

$$\delta q = \chi(\Delta q)$$

$$\delta \mu = \chi(\Delta \mu)$$

$$\delta V = \chi(\Delta V)$$

$$\delta \tilde{T} = \chi(\Delta \tilde{T})$$

RETURN

Development of Equations:

The expressions for the changes in the osculating elements due to drag have been based on the formulation appearing in The Orbital Flight Handbook, NASA SP-33 (see Reference). The appropriate pages are reproduced in Appendix II. In this theory, expressions are derived for the changes in the elements $(a, e, i, \Omega, \omega)$ over one revolution; the following assumptions are made:

(1) The density is assumed to be spherically symmetric and to change exponentially above perigee.

(2) The satellite is assumed to move along the unperturbed Keplerian orbit for the integration range of one orbit.

(3) The atmosphere rotates with the Earth at a uniform angular rate.

Changes in the classic elements $(a, e, i, \Omega, \omega)$ can be related to changes in the nonsingular elements through the following relations:

$$\Delta a = \Delta a$$

$$\Delta p = \cos i \sin \Omega (\Delta i) + q (\Delta \Omega)$$

$$\Delta q = \cos i \cos \Omega (\Delta i) - p (\Delta \Omega)$$

$$\Delta \mu = \sin \tilde{\omega} (\Delta e) + \nu (\Delta \Omega + \Delta \omega)$$

$$\Delta \nu = \cos \tilde{\omega} (\Delta e) - \mu (\Delta \Omega + \Delta \omega)$$

$$\Delta T = \frac{-(\Delta \omega + \Delta \Omega)}{n}$$

These changes are "per revolution" and are multiplied by

$$\frac{\theta_1 - \theta_0}{2\pi};$$

to yield the changes during the time period, $t_1 - t_0$.

Reference: Townsend, G. W., "Perturbations," Chapter IV, The Orbital Flight Handbook, NASA SP-33, Volume 1, Part 1 (1963).

```
      SUBROUTINE DRAG (A,P,Q,MU,NU,DDA,DDP,DDQ,DDM,DDN,DDT,TO,T1,AMOT,  DRAG0010
     1 WCDA)                                                            DRAG0020
C                                                                       DRAG0030
      REAL MU,NU                                                        DRAG0040
C                                                                       DRAG0050
C        THIS ROUTINE COMPUTES THE SECULAR PERTURBATIONS IN THE         DRAG0060
C        OSCULATING ELEMENTS DUE TO DRAG.  THE FORMULATION IS TAKEN     DRAG0070
C        FROM 'ORBITAL FLIGHT HANDBOOK' NASA SP-33, VOLUME 1, PART1,    DRAG0080
C        PAGE  IV-40.                                                   DRAG0090
C        NOMENCLATURE                                                   DRAG0100
C           WCDA   = THE BALLISTIC COEFFICIENT, W/(CD*A) IN POUNDS PER  DRAG0110
C                    SQUARE FOOT                                        DRAG0120
C           HP     = SCALE HEIGHT AT PERIGEE                            DRAG0130
C           RHO    = AIR DENSITY IN POUNDS PER CUBIC FOOT               DRAG0140
C           RHOP   = AIR DENSITY AT PERIGEE                             DRAG0150
C           DDA    = CHANGE IN SEMI MAJOR AXIS                          DRAG0160
C           DDE    = CHANGE IN ECCENTRICITY                             DRAG0170
C           DDI    = CHANGE IN INCLINATION                              DRAG0180
C           DDNOD  = CHANGE IN NODE                                     DRAG0190
C           DDW    = CHANGE IN LONGITUDE OF PERIGEE                     DRAG0200
C           DDM    = CHANGE IN MU                                       DRAG0210
C           DDN    = CHANGE IN NODE                                     DRAG0220
C           DDP    = CHANGE IN P                                        DRAG0230
C           DDQ    = CHANGE IN Q                                        DRAG0240
C                                                                       DRAG0250
C                                                                       DRAG0260
C                                                                       DRAG0270
C                                                                       DRAG0280
      COMMON /ASTRO/ GCON, AJ, RE, RP                                   DRAG0290
C                                                                       DRAG0300
      DATA  TWOPI,PI,ROT  /6.2831853, 3.1415926, .729211505E-4/         DRAG0200
C                                                                       DRAG0330
C        PRELIMINARY CONSTANTS                                          DRAG0340
C                                                                       DRAG0350
      SINI   = SQRT (P*P + Q*Q)                                         DRAG0370     2
      COSI   = SQRT (1. - SINI*SINI)                                    DRAG0380     3
```

```
      E2      = MU*MU + NU*NU                                    DRAG0390
      E       = SQRT (E2)                                        DRAG0400   4
      IF (E .EQ. 0.) GO TO 60                                    DRAG0410
      SINWIG = MU/E                                              DRAG0420
      COSWIG = NU/E                                              DRAG0430
      WWIG   = ATAN2 (SINWIG,COSWIG)                             DRAG0440   8
      GO TO 65                                                   DRAG0450
   60 SINWIG = 0.                                                DRAG0460
      COSWIG = 0.                                                DRAG0470
      WWIG   = 0.                                                DRAG0480
C                                                                DRAG0490
   65 IF (SINI .EQ. 0.) GO TO 70                                 DRAG0500
      CICN   = COSI/SINI * Q                                     DRAG0510
      CISN   = COSI/SINI * P                                     DRAG0520
      XNOD   = ATAN2 (CISN,CICN)                                 DRAG0530  14
      GO TO 100                                                  DRAG0540
   70 CICN   = 0.                                                DRAG0550
      CISN   = 0.                                                DRAG0560
      XNOD   = 0.                                                DRAG0570
C                                                                DRAG0580
C        BEGIN THE DRAG COMPUTATION                              DRAG0590
C                                                                DRAG0600
  100 WW     = WWIG - XNOD                                       DRAG0610
      SINW   = SIN(WW)                                           DRAG0620  18
      COSW   = COS(WW)                                           DRAG0630  19
      COSW2  = COSW * COSW                                       DRAG0640
      B      = .5 / WCDA                                         DRAG0650
      HPERIG = A*(1.-E)                                          DRAG0660
      ESP    = MU*Q - NU*P                                       DRAG0670
      DEN    = 1./(RE*RE) + (ESP/RP)**2                          DRAG0680
      RERTH  = SQRT (1./DEN)                                     DRAG0690  20
      HPERIG = HPERIG - RERTH                                    DRAG0700
      HP     = 400. * (169. + HPERIG/3281.)                      DRAG0710
      RHOP   = DENSIT (HPERIG)                                   DRAG0720  21
      F      = 1. - 2.*ROT/AMOT * (1.-E)*SQRT((1.-E)/(1.+E))* COSI  DRAG0730  22
      C     = A*E/HP                                             DRAG0740
C                                                                DRAG0750
```

```
      IF (C .LT. 2.) GO TO 300                                           DRAG0760
C                                                                        DRAG0770
C        COMPUTE CHANGES IN CLASSIC ORBITAL ELEMENTS WHEN AE/H .GE. 2.  DRAG0780
C                                                                        DRAG0790
      FSTR   = E/(1.-E2) * (E +(F-1.)/SQRT(F))                           DRAG0800    26
      QQ     = 2.*B*RHOP*A*A*F * (1.+E)**2/SQRT(1.-E2) * SQRT(TWOPI/C)  DRAG0810    27    28
      D      = TWOPI*B*ROT/AMOT *A*RHOP*SQRT(F) / SQRT(TWOPI*C)          DRAG0820
C                                                                        DRAG0830    29    30
      DDA    = -QQ * (1. + (1. -8.*E + 3.*E2)/(8.*C*(1.-E2)))            DRAG0840
      DDE    = -QQ * (1.-E)/A * (1. - (3.+4.*E-3.*E2)/(8.*C*(1.-E2)))    DRAG0850
      DDI    = -D*(1.-E)**2 * (COSW2 + 1./8./C * (8.*(1.+E)/(1.-E)       DRAG0860
     1         + (4.*FSTR + (9.*E2+6.*E-15.)/(1.-E)**2)*COSW2))*SINI     DRAG0870
      DDNOD  = -D*(1.-E)**2 * (1. +1./8./C * (4.*FSTR + (9.*E2+6.*E-15.)DRAG0880
     1          /(1.-E)**2))*SINW*COSW                                   DRAG0890
      DDW    = -DDNOD*COSI                                               DRAG0900
      GO TO 500                                                          DRAG0910
C                                                                        DRAG0920
C                                                                        DRAG0930
C        COMPUTE CHANGES IN ELEMENTS WHEN  AE/H  .LT. 2.                 DRAG0940
C                                                                        DRAG0950
  300 BESIO  = BESEL (C,0,2)                                             DRAG0960    33
      BESI1  = BESEL (C,1,2)                                             DRAG0970    34
      BESI2  = BESEL (C,2,2)                                             DRAG0980    35
      XK     = PI   /WCDA * ROT/AMOT * A*RHOP*SQRT(F)*EXP(-C)            DRAG0990    36    37
      G      = PI/WCDA * A*A * RHOP*F * EXP(-C) * 2.                     DRAG1000
C                                                                        DRAG1010    38
      DDA    = -G*(1.+E)* SQRT((1.+E)/(1.-E)) * ((1.-2.*E)*BESIO + 2.*E*DRAG1020
     1         BESI2)                                                    DRAG1030    39
      DDE    = -G/A * SQRT((1.+E)/(1.-E)) * ((1.-E)*BESI1 + E/2. *       DRAG1040
     1         (BESIO + BESI2))                                          DRAG1050    40
      DDI    = -XK * (.5*(BESIO - BESI2) + COSW**2 * (BESI2 - 2.*E*      DRAG1060
     1         BESI1))*SINI                                              DRAG1070
      DDNOD  = -XK * (BESI2 - 2.*E*BESI1) * SINW*COSW                    DRAG1080
      DDW    = -COSI*DDNOD                                               DRAG1090
C                                                                        DRAG1100
C        COMPUTE CHANGES IN THE NONSINGULAR ELEMENTS                     DRAG1110
C                                                                        DRAG1120
```

```
  500 DDM     = SINWIG*DDE + NU*(DDNOD + DDW)                           DRAG1130
      DDN     = COSWIG*DDE - MU*(DDNOD + DDW)                           DRAG1140
      DDP     = CISN*DDI + Q*DDNOD                                      DRAG1150
      DDQ     = CICN*DDI - P*DDNOD                                      DRAG1160
C                                                                       DRAG1170
      DDT     = -(DDW+DDNOD) / AMOT                                     DRAG1180
C                                                                       DRAG1190
C        COMPUTE THE CHANGES IN THE NONSINGULAR ELEMENTS OVER THE       DRAG1200
C        SPECIFIED TIME INTERVAL , T1 -T0.                              DRAG1210
C                                                                       DRAG1220
      XXX     = (T1-T0)*AMOT/6.2831852                                  DRAG1230
C                                                                       DRAG1240
      DDA     = DDA*XXX                                                 DRAG1250
      DDM     = DDM*XXX                                                 DRAG1260
      DDN     = DDN*XXX                                                 DRAG1270
      DDP     = DDP*XXX                                                 DRAG1280
      DDQ     = DDQ*XXX                                                 DRAG1290
      DDT     = DDT*XXX                                                 DRAG1300
      RETURN                                                            DRAG1310
      END                                                               DRAG1320
```

SUBROUTINE DRAG

COMMON VARIABLES

COMMON BLOCK ASTRO   ORIGIN C0001   LENGTH 00004

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
GCON	00000	R	AJ	00001	R	RE	00002	R
RP	00003	R						

UNDIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
SINI	00005	R	COSI	00006	R	E2	00007	R
E	00010	R	SINWIG	00011	R	COSWIG	00012	R
WWIG	00013	R	CICN	00014	R	CISN	00015	R
XNOD	00016	R	WW	00017	R	SINW	00020	R
COSW	00021	R	COSW2	00022	R	B	00023	R
HPERIG	00024	R	ESP	00025	R	DEN	00026	R
RERTH	00027	R	HP	00030	R	RHOP	00031	R
F	00032	R	ROT	00033	R	C	00034	R
FSTR	00035	R	QQ	00036	R	TWOPI	00037	R
D	00040	R	DDE	00041	R	DDI	00042	R
DDNOD	00043	R	DDW	00044	R	BESI0	00045	R
BESI1	00046	R	BESI2	00047	R	XK	00050	R
PI	00051	R	G	00052	R	XXX	00053	R

ENTRY POINTS

DRAG   SECTION   5

SUBROUTINES CALLED

DRAGG STORAGE MAP

SQRT	SECTION	6	ATAN2	SECTION	7	SIN	SECTION	8
COS	SECTION	9	DENSIT	SECTION	10	BESEL	SECTION	11
EXP	SECTION	12	SYSLOC	SECTION	13			

EFN IFN CORRESPONDENCE

EFN	IFN	LOCATION	EFN	IFN	LOCATION	EFN	IFN	LOCATION
50	10A	00167	65	11A	00172	70	16A	00215
100	17A	00220	300	32A	00730	500	41A	01207

DECK LENGTH IN OCTAL IS 01430.

Subroutine DENSIT

Purpose: This subroutine computes the atmospheric density in pounds per cubic foot

Deck Name: DENST

Calling Sequence: RHØ = DENSIT (H)

Subroutines Called: NONE

Functions Called: ALØG (logarithm)
EXP (exponential)

Deck Length: 00136_8

Input/Output:

I/O	FØRTRAN Name	Math Name	Dimension	Common/ Argument	Definition
I	H	h	1	Arg	altitude above reference geoid
I	ALT	A_l	1	ATMØS	lowest altitude tabulated in density table
I	STEP	S	1	ATMØS	distance between values in density table
I	DENS(M)	ρ_M	36	ATMØS	tabulated values of density
Ø	RHØ	ρ	1		density at h

Development of Equations:

This routine interpolates a 36 point table to compute the atmospheric density in pounds per cubic feet. Densitiss between 500,000 feet and 1,500,000 feet are tabulated in steps of 30,000; feet below 500,000 feet an error message is printed and above 1,500,000 feet the density is zeroed. The computation proceeds as follows: Let h be the altitude; then the distance, Δh, between h and the nearest lower tabulated altitude is computed first. The number of tabulated altitudes below h is

$$m = \frac{h - 500,000}{30,000} + 1$$

The number of intervals of 30,000 feet below h is

$$x = m - 1$$

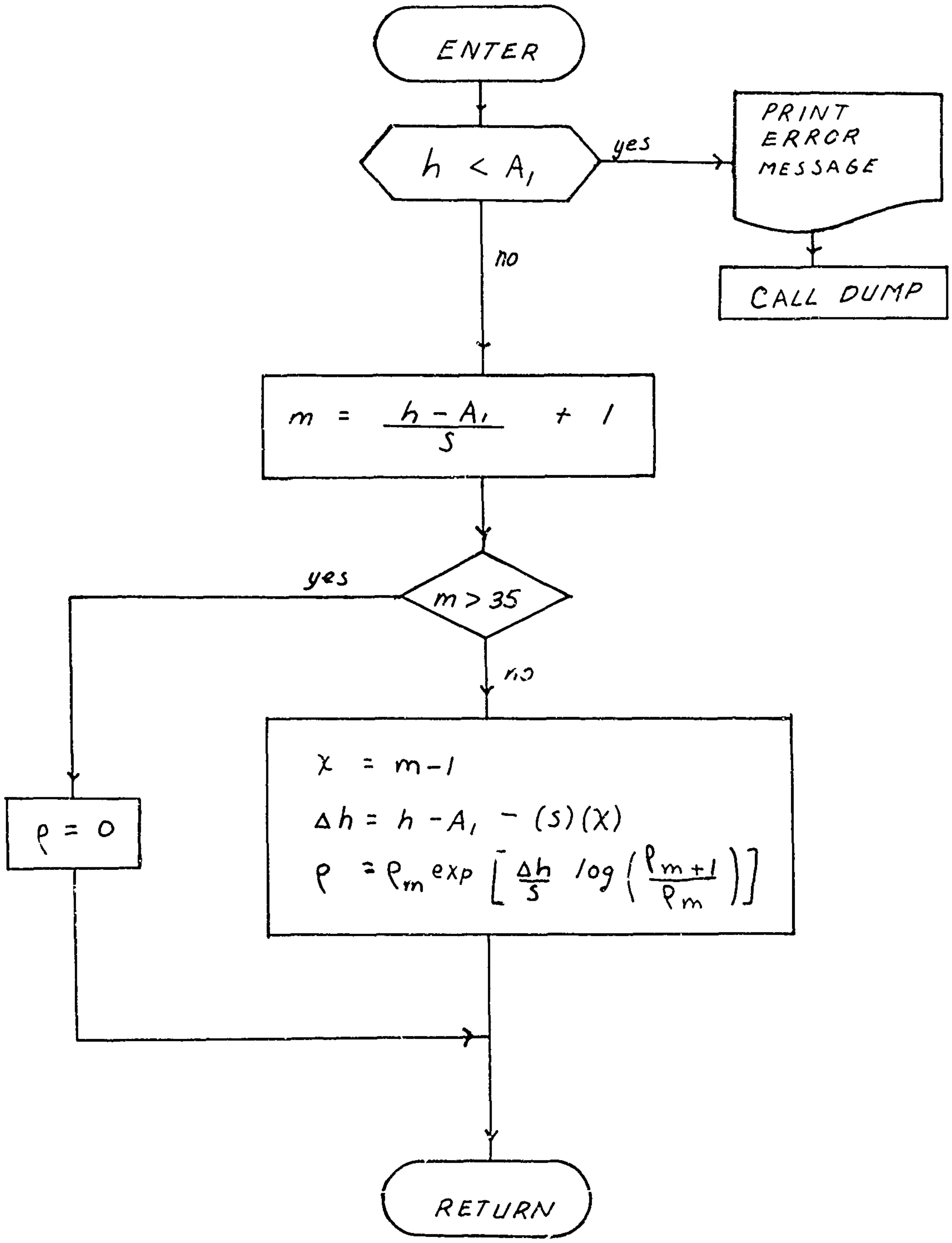
Then

$$\Delta h = h - 500,000 - (30,000)\, x$$

The density at h is computed assumming an exponential variation between the m and $m+1$ point

$$\rho = \rho_m \exp\left[\frac{\Delta h}{30,000} \log\left(\frac{\rho_{m+1}}{\rho_m}\right)\right]$$

function DENSIT



```
         DENST       -  EFN   SOURCE STATEMENT  -  IFN(S)  -

      FUNCTION DENSIT (H)                                                DEN00010
C                                                                        DEN00020
C        THIS ROUTINE COMPUTES THE ATMOSPHERIC DENSITY IN POUNDS PER     DEN00030
C        CUBIC FOOT AT ALTITUDES BETWEEN 500,000 FT AND 1,550,000 FT.    DEN00040
C        AN INTERPOLATION IS MADE BETWEEN ENTRIES IN A 36 POINT TABLE,   DEN00050
C        THE POINTS BEING 30,000 FEET APART.  AN EXPONENTIAL VARIATION   DEN00060
C        BETWEEN THE POINTS IS ASSUMED.                                  DEN00070
C                                                                        DEN00080
      COMMON  /ATMOS/ ALT,STEP,DENS(36)                                  DEN00090
C                                                                        DEN00100
      IF (H .GE. ALT) GO TO 50                                           DEN00110
  200 WRITE (6,210) H,ALT                                                DEN00120    5
  210 FORMAT ( 70H EXECUTION STOPPED.  ALTITUDE LESS THAN LOWEST ENTRY   DEN00130
     1N DENSITY TABLE   / 9H H     =  E17.8  /  9H LIMIT =  E17.8)       DEN00140
      CALL DUMP                                                          DEN00150
C                                                                        DEN00160    6
   50 M       = (H - ALT) / STEP + 1.                                    DEN00170
      IF (M .GT. 35) GO TO 100                                           DEN00180
      XX      = M-1                                                      DEN00190
      DH      = (H - ALT) - XX*STEP                                      DEN00200
      C       = DENS(M+1)/DENS(M)                                        DEN00210
      CC      = ALOG(C)                                                  DEN00220    14
      CCC     = CC * DH / STEP                                           DEN00230
      CCCC    = EXP(CCC)                                                 DEN00240    15
      DENSIT = DENS(M) * CCCC                                            DEN00250
      RETURN                                                             DEN00260
C                                                                        DEN00270
  100 DENSIT = 0.                                                        DEN00280
      RETURN                                                             DEN00290
      END                                                                DEN00300
```

DENST STORAGE MAP

FUNCTION DENSIT TYPE R

COMMON VARIABLES

COMMON BLOCK ATMOS ORIGIN 00001 LENGTH 00046

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
ALT	00000	R	STEP	00001	R	DENS	00002	R

UNDIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
F.0000	00047	R	M	00050	I	XX	00051	R
DH	00052	R	C	00053	R	CC	00054	R
CCC	00055	R	CCCC	00056	R			

ENTRY POINTS

DENSIT SECTION 5

SUBROUTINES CALLED

.FWRD.	SECTION	6	DUMP	SECTION	7	ALOG	SECTION	8
EXP	SECTION	9	.UN06.	SECTION	10	.FFIL.	SECTION	11
.FCNV.	SECTION	12	E.1	SECTION	13	E.2	SECTION	14
E.3	SECTION	15	E.4	SECTION	16	CC.1	SECTION	17
CC.2	SECTION	18	CC.3	SECTION	19	CC.4	SECTION	20
SYSLOC	SECTION	21						

SID 65-1203-3

EFN IFN CORRESPONDENCE

EFN	IFN	LOCATION	EFN	IFN	LOCATION	EFN	IFN	LOCATION

DENST STORAGE MAP

```
50        7A      00136    200        5A       00121    210       FORMAT    00070
100       17A     00224
  DECK LENGTH IN OCTAL IS     00204.
```

Subroutine VECT

Purpose: To determine the position and velocity vectors corresponding to a given θ and a given set of orbital elements.

Deck Name: VECTT

Calling Sequence: VECT (A, MU, NU, P, Q, THETA, RVEC, VVEC, SGN)

Subroutines Called: NONE

Functions Called: SQRT
SIN
CØS

Deck Length: 00402_8

Input/Output:

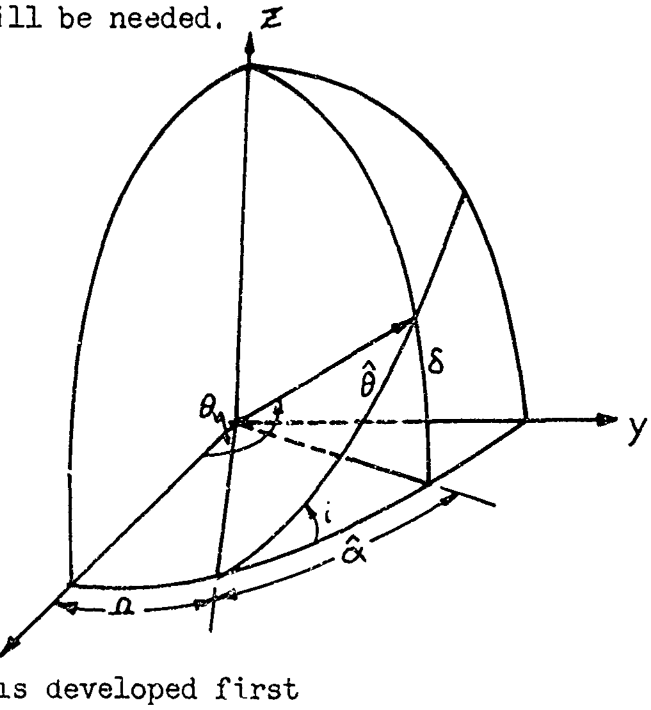
I/O	FØRTRAN Name	Math Name	Dimension	Common/ Argument	Definition
I	A	a	1	Arg	semi-major axis
I	MU	μ	1	Arg	$\mu = e \sin \tilde{\omega}$
I	NU	ν	1	Arg	$\nu = e \cos \tilde{\omega}$
I	P	p	1	Arg	$p = \sin i \sin \Omega$
I	Q	q	1	Arg	$q = \sin i \cos \Omega$
I	THETA	θ	1	Arg	$\theta = f + \tilde{\omega}$
Ø	RVEC	$\vec{R}$	3	Arg	position vector
Ø	VVEC	$\dot{\vec{R}}$	3	Arg	velocity vector
I	SGN		1	Arg	= + 1 for posigrade orbit - 1 for retrograde orbit
I	GCØN	k	1	ASTRØ	gravitational constant of the Earth ($\text{Length}^3/\text{Time}^2$)

I/O	FØRTRAN Name	Math Name	Dimension	Common/ Argument	Definition
I	AJ	J	1	ASTRØ	first harmonic in Jeffrey's gravitational potential
I	RE	R_E	1	ASTRØ	equatorial radius of the Earth
I	RP	R_P	1	ASTRØ	polar radius of the Earth

Development of Equations:

This routine determines the position and velocity vectors corresponding to a given set of osculating elements and θ.

First, the position vector will be determined. The following relations. from the sketch and spherical trigonometry, will be needed.



$$\theta = \Omega + \hat{\theta}$$

$$\alpha = \Omega + \hat{\alpha}$$

$$\cos\hat{\alpha} = \frac{\cos\hat{\theta}}{\cos\delta}$$

$$\sin\hat{\alpha} = \frac{\sin\delta}{\cos\delta}\ \frac{\cos i}{\sin i}$$

$$\sin\hat{\theta} = \frac{\sin\delta}{\sin i}$$

The expression for the third component, z, is developed first

$$\frac{z}{r} = \sin\delta = \sin\hat{\theta}\sin i$$

setting $\hat{\theta} = \theta - \Omega$

$$\frac{z}{r} = \sin i \left[\sin(\theta - \Omega)\right]$$

$$= \sin i \cos \Omega \sin \theta - \sin i \sin \Omega \cos \theta$$

and, in terms of p and q

$$z = r\left[q \sin \theta - p \cos \theta\right] \qquad (1)$$

Consider next, the first component of the position, X,

$$\frac{X}{r} = \cos \alpha \cos \delta = \cos(\Omega + \hat{\alpha}) \cos \delta$$

$$= (\cos \Omega \cos \hat{\alpha} - \sin \Omega \sin \hat{\alpha}) \cos \delta$$

Substituting for $\cos \hat{\alpha}$ and $\sin \hat{\alpha}$

$$\frac{X}{r} = \left[\cos \Omega \frac{\cos \hat{\theta}}{\cancel{\cos \delta}} - \frac{\sin \Omega \sin \delta \cos i}{\cancel{\cos \delta} \sin i}\right] \cancel{\cos \delta}$$

$$= \cos \Omega \cos \hat{\theta} - \sin \Omega \cos i \sin \hat{\theta}$$

adding and subtracting $\sin \Omega \sin \hat{\theta}$,

$$\frac{X}{r} = \cos \Omega \cos \hat{\theta} - \sin \Omega \sin \hat{\theta} + \sin \Omega \sin \hat{\theta}$$

$$- \sin \Omega \cos i \sin \hat{\theta}$$

$$= \cos(\hat{\theta} + \Omega) + \sin \Omega \frac{\sin \delta}{\sin i} (1 - \cos i)$$

$$= \cos \theta + \sin \delta \sin \Omega \frac{\sin i}{1 + \cos i}$$

$$= \cos \theta + \left(\frac{p}{1 + \cos i}\right) \sin \delta$$

next substitute equation (1) remembering that $\frac{z}{r} = \sin \delta$

$$\frac{x}{r} = \cos\theta + \left(\frac{p}{1+\cos i}\right)\left[q \sin\theta - p\cos\theta\right]$$

Finally

$$x = r\left[\left(1 - \frac{p^2}{1+\cos i}\right)\cos\theta + \left(\frac{pq}{1+\cos i}\right)\sin\theta\right] \tag{2}$$

a similar computation shows that

$$y = r\left[\left(1 - \frac{q^2}{1+\cos i}\right)\sin\theta + \left(\frac{pq}{1+\cos i}\right)\cos\right] \tag{3}$$

in equations (1), (2) and (3)

$$r = \frac{a(1-e^2)}{1+e\cos f} = \frac{a(1-\mu^2+\nu^2)}{1+\nu\cos\theta+\mu\sin\theta} \tag{4}$$

Equations (1), (2), (3) and (4) determine the position from a, p, q, μ, ν and θ.

The velocity vector can be found by differentiating the position vector with respect to time.

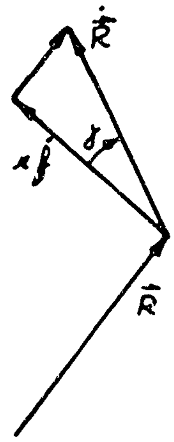
$$\dot{x} = \dot{r}\left(\frac{x}{r}\right) - r\dot{\theta}\left[\left(1+\frac{p^2}{1+\cos i}\right)\sin\theta - \left(\frac{pq}{1+\cos i}\right)\cos\theta\right]$$

$$\dot{y} = \dot{r}\left(\frac{y}{r}\right) + r\dot{\theta}\left[\left(1 - \frac{q^2}{1+\cos i}\right)\cos\theta - \left(\frac{pq}{1+\cos i}\right)\sin\theta\right] \tag{5}$$

$$\dot{z} = \dot{r}\left(\frac{z}{r}\right) + r\dot{\theta}\left[q\cos\theta + p\sin\theta\right]$$

However, the quantities $\dot{r}$ and $r\dot{\theta}$ must be determined. Since the position and velocity occur in the instantaneous osculating ellipse, the derivatives $\dot{r}$ and $\dot{\theta}$ are taken in the osculating ellipse. In particular $\dot{\theta} = \dot{f}$.

From the sketch



$$r\dot{f} = V\cos\gamma$$

where $V = |\dot{\vec{R}}|$

The angular momentum is

$$h = \sqrt{ka(1-e^2)} = \sqrt{ka(1-\mu^2-\nu^2)} = rV\cos\gamma$$

Therefore

$$r\dot{\theta} = r\dot{f} = \frac{\sqrt{ka(1-\mu^2-\nu^2)}}{r} \qquad (6)$$

To evaluate $\dot{r}$, differentiate

$$r = \frac{a(1-e^2)}{1+e\cos f}$$

to obtain

$$\dot{r} = \frac{r(e\cos f)}{a(1-e^2)}(r\dot{f})$$

and substitute equation (6)

$$\dot{r} = \frac{r(e\cos f)}{a(1-\mu^2-\nu^2)}\left[\frac{\sqrt{ka(1-\mu^2-\nu^2)}}{r}\right]$$

$$= \sqrt{\frac{k}{a(1-\mu^2-\nu^2)}}\, e\cos f = \sqrt{\frac{k}{a(1-\mu^2-\nu^2)}}\, e\cos(\theta-\tilde{W})$$

finally

$$\dot{r} = \sqrt{\frac{k}{a(1-\mu^2-\nu^2)}}\,(\nu\sin\theta-\mu\cos\theta) \qquad (7)$$

Equations (6) and (7) determine $r\dot{\theta}$ and $\dot{r}$, and all the quantities in equation (5) are known.

SUBROUTINE VECT

enter

$$r = \frac{a(1-\mu^2-\nu^2)}{1+\nu\cos\theta+\mu\sin\theta}$$

$$\left.\begin{aligned} A &= \frac{q}{1\pm\sqrt{1-p^2-q^2}} \\ B &= \frac{p}{1\pm\sqrt{1-p^2-q^2}} \end{aligned}\right\} \text{use } \begin{array}{ll} + \text{ if} & 0 \le i \le 90 \\ - \text{ if} & 90 \le i \le 180 \end{array}$$

$$\dot{r} = \sqrt{\frac{K_E}{a(1-\mu^2-\nu^2)}}\,(\nu\sin\theta-\mu\cos\theta)$$

$$r\dot{\theta} = \sqrt{K_E a(1-\mu^2-\nu^2)}\left(\frac{1}{r}\right)$$

$$x = r[(1-pB)\cos\theta + qB\sin\theta]$$

$$y = r[(1-qA)\sin\theta + pA\cos\theta]$$

$$z = r[q\sin\theta - p\cos\theta]$$

$$\dot{x} = \dot{r}\left(\frac{x}{r}\right) - (r\dot{\theta})[(1-pB)\sin\theta - qB\cos\theta]$$

$$\dot{y} = \dot{r}\left(\frac{y}{r}\right) + (r\dot{\theta})[(1-qA)\cos\theta - pA\sin\theta]$$

$$\dot{z} = \dot{z}\left(\frac{z}{r}\right) + (r\dot{\theta})[q\cos\theta + p\sin\theta]$$

Return

```
      SUBROUTINE VECT (A, MU, NU, P, Q, THETA, RVEC, VVEC, SGN)              VECT0010
C                                                                            VECT0020
      REAL MU, NU                                                            VECT0030
C                                                                            VECT0040
C        THIS ROUTINE COMPUTES THE POSITION AND VELOCITY VECTORS             VECT0050
C        CORRESPONDING TO THE ORBITAL ELEMENTS  A, MU, NU, P, Q, THETA.      VECT0060
C        SGN =  1. FOR COUNTERCLOCKWISE ORBITS                               VECT0070
C        SGN = -1. FOR CLOCKWISE ORBITS                                      VECT0080
C                                                                            VECT0090
      DIMENSION RVEC(3), VVEC(3)                                             VECT0100
      COMMON /ASTRO/ GCON, AJ, RE, RP                                        VECT0110
C                                                                            VECT0120
      CONE    = A * (1. - MU**2 - NU**2)                                     VECT0130
      COSS    = SQRT (1. - P**2 - Q**2)                                      VECT0140   2
      CONI    = 1. + SGN*COSS                                                VECT0150
      ST      = SIN(THETA)                                                   VECT0160   3
      CT      = COS(THETA)                                                   VECT0170
C                                                                            VECT0180   4
      RR      = CONE / (1. + NU*CT + MU*ST)                                  VECT0190
      AA      = Q / CONI                                                     VECT0200
      BB      = P / CONI                                                     VECT0210
      RDOT    = SQRT (GCON  / CONE) * (NU*ST - MU*CT)                        VECT0220   5
      RTHDOT  = SQRT(GCON  * CONE) / RR                                      VECT0230   6
      F1      = 1. - P*BB                                                    VECT0240
      F2      = 1. - Q*AA                                                    VECT0250
      F3      = Q*BB                                                         VECT0260
      F4      = P*AA                                                         VECT0270
C                                                                            VECT0280
      RVEC(1) = RR * (F1*CT + F3*ST)                                         VECT0290
      RVEC(2) = RR * (F2*ST + F4*CT)                                         VECT0300
      RVEC(3) = RR * (Q*ST - P*CT)                                           VECT0310
C                                                                            VECT0320
      VVEC(1) = RDOT*RVEC(1)/RR - RTHDOT * (F1*ST - F3*CT)                   VECT0330
      VVEC(2) = RDOT*RVEC(2)/RR + RTHDOT * (F2*CT - F4*ST)                   VECT0340
      VVEC(3) = RDOT*RVEC(3)/RR + RTHDOT * (Q*CT + P*ST)                     VECT0350
C                                                                            VECT0360
```

```
      RETURN                                                     VECT0370
      END                                                        VECT0380
```

SUBROUTINE VECT

COMMON VARIABLES

COMMON BLOCK ASTRO   ORIGIN 00001   LENGTH 00004

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
GCON	00000	R	AJ	00001	R	RE	00002	R
RP	00003	R						

UNDIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
CONE	00005	R	COSS	00006	R	CONI	00007	R
ST	00010	R	CT	00011	R	RR	00012	R
AA	00013	R	BB	00014	R	ROOT	00015	R
RTHDOT	00016	R	F1	00017	R	F2	00020	R
F3	00021	R	F4	00022	R			

ENTRY POINTS

VECT SECTION 5

SUBROUTINES CALLED

SQRT SECTION 6		SIN	SECTION 7	COS	SECTION 8
SYSLOC SECTION 9					

EFN IFN CORRESPONDENCE

EFN	IFN	LOCATION	EFN	IFN	LOCATION	EFN	IFN	LOCATION

DECK LENGTH IN ØCTAL IS 00402.

Subroutine TRAK

Purpose: To determine which of the several tracking stations under consideration is capable of observing the vehicle, and to compute range, range rate, azimuth and elevation of the vehicle relative to any visible station.

Deck Name: TRACK

Calling Sequence: ŞUBRØUTINE TRAK (RDATE, VDATE, TW, TF, NUMBER)

Subroutines Called: GHA
UNIT
CRØŞŞ

Functions Called: AMAG (vector magnitude)
DØT (dot product)
ATAN (arctangent)

Deck Length 00501_8

I/O	FØRTRAN Name	Math Name	Dimension	Common/ Argument	Description
I	RDATE	$\vec{R}$	3	Arg	Vehicle position vector.
I	VDATE	$\vec{V}$	3	Arg	Vehicle velocity vector.
I	TW	T_w	1	Arg	Whole number part of Julian date.
I	TF	T_f	1	Arg	Fractional part of Julian date.
I	NUMBER	N	1	Arg	Number of tracking stations considered.
I	STATN	S_T	40	TRAŞT	Tracking station data for a maximum of 10 stations. The data is arranged in groups of 4, i.e., latitude, longitude, altitude, and station name.
I	HØRCØR	H_c	10	TRAŞT	Horizon correction in case horizon is not at 0° elevation.
I	GCØN	k_E	1	ASTRØ	Gravitational constant of Earth.

I/O	FØRTRAN Name	Math Name	Dimension	Common/ Argument	Description
I	AJ	J	1	AØTRØ	First harmonic in Earth's gravitational potential.
I	RE	R_E	1	AØTRØ	Earth's equatorial radius.
I	RP	R_P	1	AØTRØ	Earth's polar radius.

Description of Equations:

The Greenwich hour angle and the rotation rate of the Earth are computed in the subroutine GHA, which is called immediately after entering TRAK. The following procedure is followed once for each tracking station under consideration. The subroutine UNIT is called to compute the position vector of the tracking station, as well as the up, east and north unit vectors at the tracking station site. Then the position of the satellite relative to the tracking station can be computed

$$\vec{\rho} = \vec{R} - R_T$$

The unit relative position vector is,

$$\hat{\rho} = \frac{\vec{\rho}}{|\vec{\rho}|}$$

If $\vec{u}$ is the up unit vector at the tracking station site, and E is the elevation

$$E = \text{Arcsin}\ (\vec{u} \cdot \hat{\rho})$$

The question of visibility can now be resolved, taking into consideration any horizon correction imposed by the geography adjacent to the tracking station. If $E < H_c$, the satellite cannot be seen by the tracking station. Note that H_c, the horizon correction, will normally be zero. If the satellite is not visible, the computation is terminated and the next tracking station (if any) is considered. If the satellite is visible, the computation continues with the azimuth determination

$$\cos \Sigma = \hat{\rho} \cdot \vec{Z}$$

$$\sin \Sigma = \hat{\rho} \cdot \vec{E}$$

when Σ is the azimuth, $\vec{Z}$ is the north unit vector, and $\vec{E}$ is the east unit vector at the tracking station site. Then

$$\Sigma = \text{Arctan} \left(\frac{\sin \Sigma}{\cos \Sigma} \right)$$

The Earth's spin vector is used to compute the velocity vector of the tracking station.

$$\vec{S}_P = (0, 0, \omega_E)$$

where ω_E is the Earth's rotation rate computed by subroutine GHA. Then the tracking station velocity is

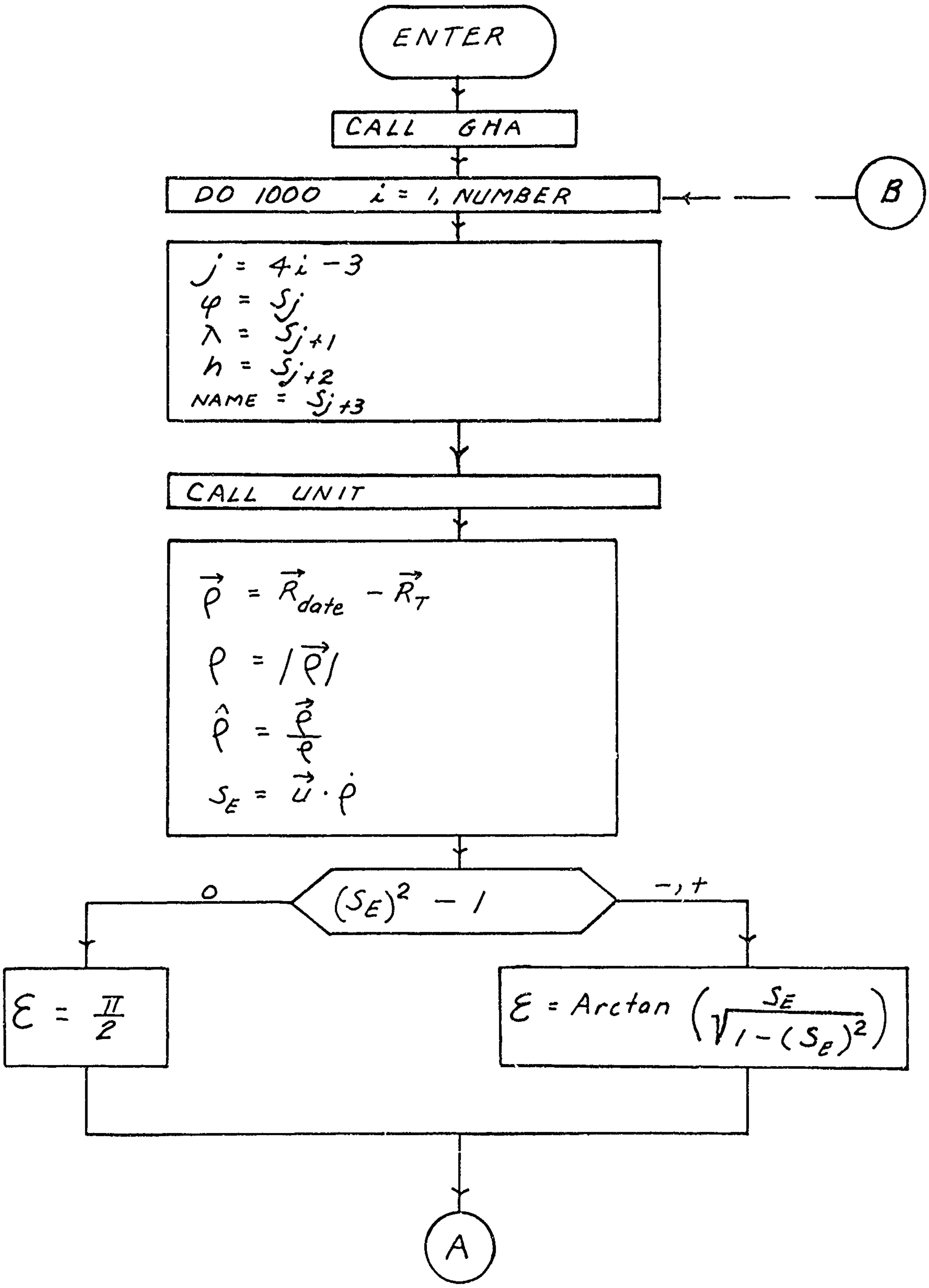
$$\vec{V}_T = \vec{S}_P \times \vec{R}_T$$

and, finally, range rate is

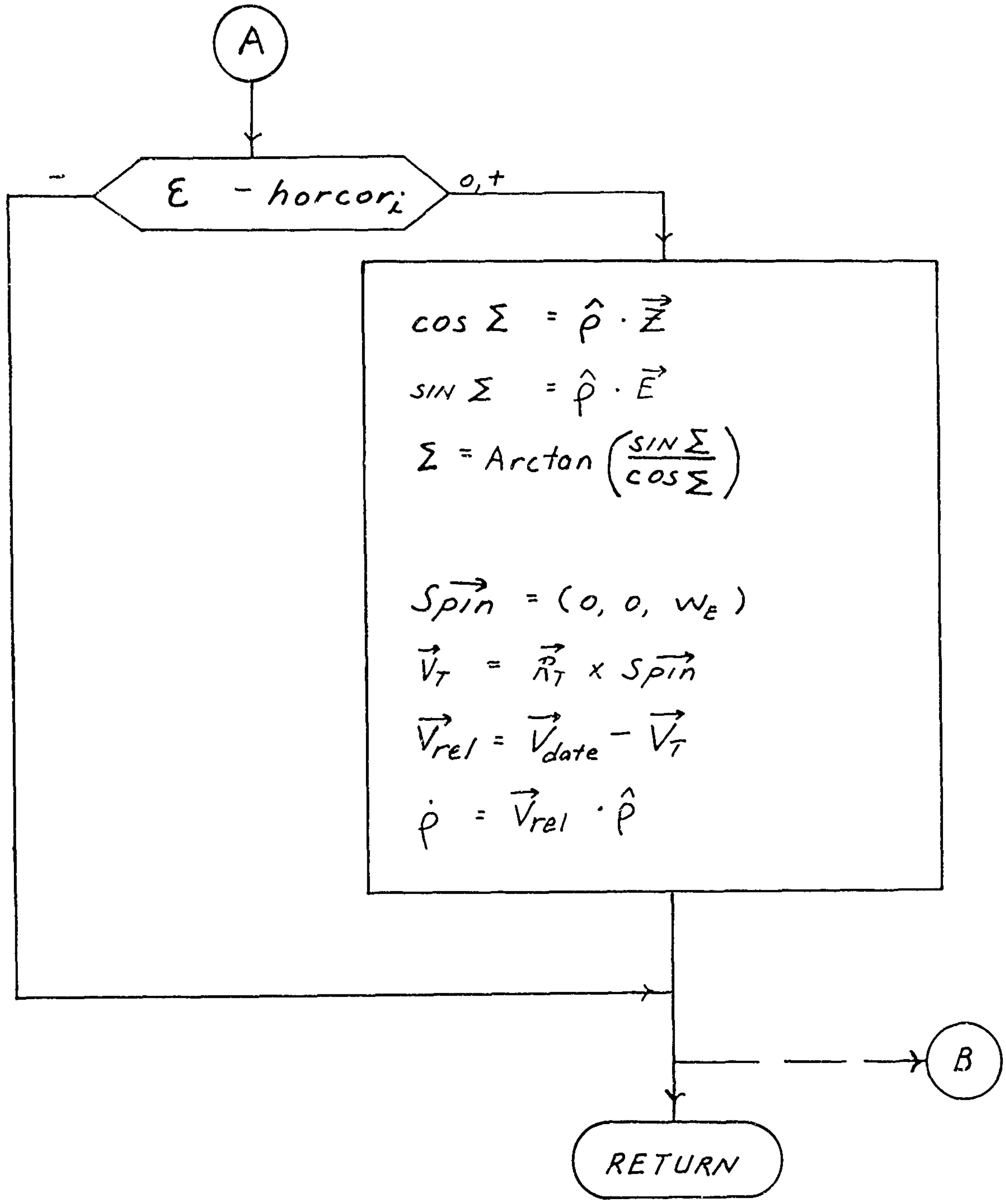
$$\dot{\vec{\rho}} = \vec{V} - \vec{V}_T$$

$$\dot{\rho} = |\dot{\vec{\rho}}|$$

SUBROUTINE TRAK



SUBROUTINE TRAK (cont.)



```
      SUBRCUTINE TRAK(RDATE,VDATE,TW,TF,NUMBER)                            TRAK0010
C                                                                          TRAK0020
C     THIS ROUTINE IS DESIGNED TO DETERMINE WHICH OF THE SEVERAL           TRAK0030
C               TRACKING STATIONS UNDER CONSIDERATION IS CAPABLE OF        TRAK0040
C               OBSERVING THE VEHICLE AT ANY TIME , AND OF COMPUTING       TRAK0050
C               THE RANGE,RANG-RATE,AZIMUTH AND ELEVATION OF THE VEHICLE   TRAK0060
C               RELATIVE TO ANY VISIBLE STATION . IF THE STATION OBSERVESTRAK0070
C               THE VEHICLE,ALL DATA ARE PRINTED OUT IN THE TOPOCENTRIC    TRAK0080
C               COORDINATE SYSTEM .                                        TRAK0090
C     RDATE = POSITION VECTOR    (FRAME OF DATE)                           TRAK0170
C     VDATE = VELOCITY VECTOR    (FRAME OF DATE)                           TRAK0180
C     TW    = WHOLE NUMBER OF DAYS FROM 0 HOURS, 1 JANUARY, 1950           TRAK0190
C     TF    = FRACTIONAL PART OF A DAY DEFINING PRESENT EPOCH .            TRAK0200
C                                                                          TRAK0250
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  TRAK0260
C                                                                          TRAK0270
      DIMENSION                          RDATE(3)          ,VDATE(3)       TRAK0280
     1              ,U(3),E(3),Z(3),RT(3),RHO(3),RUNIT(3),SPIN(3),VT(3)    TRAK0290
     2              ,VREL(3),EN(3,3)                                       TRAK0300
C                                                                          TRAK0310
      COMMON /TRAST/ STATN(40), HORCOR(10)                                 TRAK0320
      DATA CCNV1, CONV2 /86400., .0174532921/                              TRAK0330
      COMMCN /ASTRO/  GCCN, AJ, RE, RPOL                                   TRAK0340
C                                                                          TRAK0380
C                                                                          TRAK0390
C                                                                          TRAK0400
      SECOND = TF * CONV1                                                  TRAK0470
      CALL GHA( SECOND,TW,GH          ,OMEGA )                             TRAK0480    2
      OMEGA = OMEGA*CONV2                                                  TRAK0490
      GH = GH * CONV2                                                      TRAK0500
      DO 1000 I=1,NUMBER                                                   TRAK0510
  800 J = 4*I -3                                                           TRAK0520
      SLAT =STATN(J) * CONV2                                               TRAK0530
      SLCN =STATN(J+1) * CONV2                                             TRAK0540
      SALT =STATN(J+2)                                                     TRAK0550
      SNAME=STATN(J+3)                                                     TRAK0560
```

SID 65-1203-3

```
      CALL UNIT(SLAT,SLON,SALT,GH,RPOL,RE,U,E,Z,RT )                TRAK0570
C                                                                   TRAK0580
C     POSITION RELATIVE TO THE TRACKING STATION * * * * * * * * * * * * TRAK0590   13
      DO 1 K=1,3                                                    TRAK0600
    1 RHO(K) = RDATE(K) - RT(K)                                     TRAK0610
      RHCM = AMAG(RHO)                                              TRAK0620   22
      DO 2 K=1,3                                                    TRAK0630
    2 RUNIT(K) = RHO(K)/RHOM                                        TRAK0640
      SE = DOT(U,RUNIT)                                             TRAK0650   29
      IF(SE*SE-1.)  20,30,20                                        TRAK0660
   30 ELEV = 3.14159265* SIGN(.5,SE)                                TRAK0670
      GO TO 31                                                      TRAK0680
   20 ELEV = ATAN( SE/(SQRT(1.-SE**2)))                             TRAK0690   34   35
   31 IF( ELEV - HORCOR(I))  1000,4,4                               TRAK0700
    4 CAZ = DOT(RUNIT,Z)                                            TRAK0710   40
      SAZ = DOT(RUNIT,E)                                            TRAK0720   41
      AZMUTH = ATAN2 (SAZ,CAZ)                                      T9A20730
C                                                                   TRAK0740
C     VELOCITY AND RANGE-RATE RELATIVE TO TRACKER * * * * * * * * * * * TRAK0750   42
      SPIN(1)=0.                                                    TRAK0760
      SPIN(2)=0.                                                    TRAK0770
      SPIN(3)= OMEGA                                                TRAK0780
      CALL CROSS( SPIN,RT,VT )                                      TRAK0790   43
      DO 5 K =1,3                                                   TRAK0800
    5 VREL(K) = VDATE(K) - VT(K)                                    TRAK0810
      RHODOT= DOT(VREL,RUNIT )                                      TRAK0820   52
      RHCM = RHOM * .0003048
      RHCDOT = RHODOT * .0003048
      ELED = FLEV/CONV2                                             TRAK0830
      AZMUTD=AZMUTH/CONV2                                           TRAK0840
      IF (AZMUTD .LT. 0.)  AZMUTD = AZMUTD + 360.                   TRAK0845
C                                                                   TRAK0850
C     OUTPUT OF DATA * * * * * * * * * * * * * * * * * * * * * * * * *TRAK0860
      WRITE    (6,10 ) SNAME,TW,TF,(RHO(K),K=1,3),(VREL(K),K=1,3),  TRAK0870
     1          RHOM,RHODOT,AZMUTD ,ELED                            TRAK0880   54
   10 FORMAT(// 9H STATION  A6   ,21H OBSERVES VEHICLE AT 2E17.8,5H CAYSTRAK0890
     1/20H RELATIVE POSITION = 3E17.8 /20H RELATIVE VELOCITY = 3E17.8  TRAK0900
```

```
       TRACK       -  EFN   SCURCE STATEMENT  -  IFN(S)  -

    2/20H R, RUOT, AZ, ELEV = 4E17.8   )                              TRAK0910
C                                                                     TRAK0920
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * TRAK0930
C                                                                     TRAK0940
 1000 CONTINUE                                                        TRAK1020
  700 RETURN                                                          TRAK1030
      END                                                             TRAK1040
```

SUBROUTINE TRAK

COMMON VARIABLES

COMMON BLOCK TRAST ORIGIN 00001 LENGTH 00062

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
STATN	00000	R	HORCOR	00050	R			

COMMON BLOCK ASTRO ORIGIN 00063 LENGTH 00004

GCON	00000	R	AJ	00001	R	RE	00002	R
RPOL	00003	R						

DIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
U	00067	R	E	00072	R	Z	00075	R
RT	00100	R	RHO	00103	R	RUNIT	00106	R
SPIN	00111	R	VT	00114	R	VREL	00117	R
EN	00122	R						

UNDIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
SECOND	00133	R	CONV1	00134	R	GH	00135	R
OMEGA	00136	R	CCNV2	00137	R	I	00140	I
J	00141	I	SLAT	00142	R	SLON	00143	R
SALT	00144	R	SNAME	00145	R	RHOM	00146	R
SE	00147	R	ELEV	00150	R	CAZ	00151	R
SAZ	00152	R	AZMUTH	00153	R	RHODOT	00154	R
ELEC	00155	R	AZMUTD	00156	R			

ENTRY POINTS

TRAK SECTION 7

SUBROUTINES CALLED

GHA	SECTION	8	UNIT	SECTION	9	AMAG	SECTION	10
DOT	SECTION	11	ATAN	SECTION	12	SQRT	SECTION	13
ATAN2	SECTION	14	CROSS	SECTION	15	.FWRD.	SECTION	16
.UN06.	SECTION	17	.FFIL.	SECTION	18	.FCNV.	SECTION	19
SYSLOC	SECTION	20						

EFN IFN CORRESPONDENCE

EFN	IFN	LOCATION	EFN	IFN	LOCATION	EFN	IFN	LOCATION
1000	63A	00545	800	7A	00257	1	17A	00325
2	25A	00340	20	33A	00366	30	31A	00357
31	36A	00410	4	39A	00414	5	47A	00451
10	FORMAT	00176	700	66A	00547			

DECK LENGTH IN OCTAL IS 00522.

Subroutine GHA

Purpose: To compute the local hour angle relative to the mean vernal equinox.

Deck Name: GHAN

Calling Sequence: SUBROUTINE GHA (T, DD, GH, ØMEGA)

Subroutines Called: None

Functions Called: None

Deck Length: 00145_8

Input/Output:

I/O	FØRTRAN Name	Math Name	Common/ Argument	Dimension	Description
I	T	t	ARG	1	fraction of a julian day in seconds
I	DD	d	ARG	1	whole number of julian days since 1 January 1950
Ø	GH	GH	ARG	1	local hour angle
Ø	ØMEGA	ω_E	ARG	1	rotation rate of the earth

SUBROUTINE GHA

ENTER

$$W_E = \frac{.0041780742}{1 + (5.21 \times 10^{-13})\, d}$$

$$GH = 100.07554 + .98564735\, d$$
$$(2.9015 \times 10^{-13})\, d^2 + \omega_E T$$

RETURN

where

d = whole number of julian days past 0th 1 January 1950 (JD 2433282.5)

T = fraction of julian day

Development of Equations:

The hour angle of the Greenwich meridian relative to the mean vernal equinox of epoch T is given in the Nautical Almanac as

$$\gamma_m(t) = 100^\circ.07554260 + 0^\circ.9856473460d$$
$$+ (2^\circ.9015) \times 10^{-13}d^2 + wt \pmod{360}$$

where

d = the integral number of days past zero hours, 1 January 1950

t = time in seconds past zero hours of the epoch date

$$\omega = \frac{.00417807417}{1 + (5.21)10^{-13}d}$$

```
      SUBROUTINE GHA(T,DD,GH   ,OMEGA )                                GHA00020
C                                                                      GHA00030
C        THIS ROUTINE COMPUTES THE HOUR ANGLE OF GREENWICH (IN
C        DEGREES) RELATIVE TO THE MEAN VERNAL EQUINOX OF DATE.
C
C        T    = THE FRACTION OF A DAY (IN SECONDS)
C        DD   = THE WHOLE NUMBER OF JULIAN DAYS PAST 0 HOURS, 1 JANUARY,
C               1950. (JD 243 3282.5)
C                                                                      GHA00060
      OMEGA = .0041780742?(1.+5.21E-13*DD )                            GHA00080
      GH = 100.07554 + .98564735*DD + 2.9015E-13*DD*DD + OMEGA*T       GHA00090
      N = GH/360.                                                      GHA00100
      X = N                                                            GHA00110
      GH = GH - X*360.*SIGN(1.,GH )                                    GHA00120
      IF(GH) 1,2,2                                                     GHA00130
    1 GH = GH + 360.                                                   GHA00140
    2 RETURN                                                           GHA00160
      END                                                              GHA00170
```

SUBROUTINE GHA

UNDIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
N	00001	I	X	00002	R			

ENTRY POINTS

GHA	SECTION	3

SUBROUTINES CALLED

E.I	SECTION	4	E.2	SECTION	5	E.3	SECTION	6
E.4	SECTION	7	CC.1	SECTION	8	CC.2	SECTION	9
CC.3	SECTION	10	CC.4	SECTION	11	SYSLOC	SECTION	12

EFN IFN CORRESPONDENCE

EFN	IFN	LOCATION	EFN	IFN	LOCATION	EFN	IFN	LOCATION
1	4A	00102	2	5A	00105			

DECK LENGTH IN OCTAL IS 00145.

Subroutine UNIT

Purpose: To compute the up, east and north unit vectors at the tracking station.

Deck Name: UNITT

Calling Sequence: SUBRØUTINE UNIT (SLAT, SLØN, SALT, GHA, RPØL, RE, U, E, Z, RT)

Subroutines Called: None

Functions Called: SIN
SQRT

Deck Lengtn: 00254_8

Input/Output:

I/O	FØRTRAN Name	Math Name	Common/ Argument	Dimension	Description
I	SLAT	φ	ARG	1	station latitude
I	SLØN	λ	ARG	1	station longitude
I	SALT	h	ARG	1	station altitude above reference geoid
I	GHA	GHA	ARG	1	local hour angle
I	RPØL	R_p	ARG	1	earth's polar radius
I	RE	R_E	ARG	1	earth's equatorial radius
Ø	U	$\vec{u}$	ARG	3	unit zenith vector at station
Ø	E	$\vec{E}$	ARG	3	unit east vector at station
Ø	RT	$\vec{R}_T$	ARG	3	tracking station position vector

UNIT

ENTER

$$C = \sqrt{\cos^2\varphi + \left(\frac{R_P}{R_E}\right)^2 \sin^2\varphi}$$

$$\vec{U} = \begin{pmatrix} u_1 \\ u_2 \\ u_3 \end{pmatrix} = \begin{pmatrix} \cos\varphi \cos(\lambda + GHA) \\ \cos\varphi \sin(\lambda + GHA) \\ \sin\varphi \end{pmatrix}$$

$$\vec{E} = \begin{pmatrix} -\sin(\lambda + GHA \\ \cos(\lambda + GHA \\ 0 \end{pmatrix}$$

$$\vec{Z} = \begin{pmatrix} -\sin\varphi \cos(\lambda + GHA) \\ -\sin\varphi \sin(\lambda + GHA) \\ \cos(\lambda + GHA) \end{pmatrix}$$

$$\vec{R}_T = \begin{pmatrix} \left(\frac{R_E}{C} + h\right) u_1 \\ \left(\frac{R_E}{C} + h\right) u_2 \\ \left(\frac{R_P^2}{R_E C} + h\right) u_3 \end{pmatrix}$$

RETURN

```
      SUBROUTINE UNIT(SLAT,SLON,H    ,GHA,RPOL,RE,U,E,Z,RT )          UNIT0010
C                                                                     UNIT0020
C     THIS ROUTINE COMPUTES THREE UNIT VECTORS WITH ORIGIN AT THE     UNIT0030
C           TRACKING STATION AND ORIENTED UP(U),EAST(E) AND NORTH(Z).UNIT0040
C           THE ROUTINE ALSO DEFINES THE POSITION VECTOR FOR THE      UNIT0050
C           STATION IN THE TRUE EQUATOR OF DATE FRAME                 UNIT0060
C     SLAT = STATION LATITUDE ( RAD )                                 UNIT0061
C     SLON = STATION LONGITUDE( RAD )                                 UNIT0062
C     SALT = STATION ALTITUDE (UNITS OF  POLAR OR EQUATORIAL RADII )  UNIT0063
C                                                                     UNIT0070
      DIMENSION U(3),E(3),Z(3),RT(3)                                  UNIT0080
      SLA  = SIN(SLAT)                                                UNIT0090   2
      SLN  = SIN(SLON + GHA)                                          UNIT0100   3
      CLA  = COS(SLAT)                                                UNIT0110   4
      CLN  = COS(SLON + GHA)                                          UNIT0120   5
      C = SQRT( CLA*CLA +(RPOL/RE)**2*SLA*SLA )                       UNIT0130   6
      U(1) = CLA*CLN                                                  UNIT0140
      U(2) = CLA*SLN                                                  UNIT0150
      U(3) = SLA                                                      UNIT0160
      E(1) = -SLN                                                     UNIT0170
      E(2) =  CLN                                                     UNIT0180
      E(3) =  0.                                                      UNIT0190
      Z(1) =-SLA*CLN                                                  UNIT0200
      Z(2) =-SLA*SLN                                                  UNIT0210
      Z(3) = CLA                                                      UNIT0220
      RT(1)= (RE/C +H)*U(1)                                           UNIT0230
      RT(2)= (RE/C +H)*U(2)                                           UNIT0240
      RT(3)= ( RPOL*RPOL/(RE*C) +H )*U(3)                             UNIT0250
      RETURN                                                          UNIT0260
      END                                                             UNIT0270
```

STORAGE MAP

SUBROUTINE UNIT

UNDIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
SLA	00001	R	SLN	00002	R	CLA	00003	R
CLN	00004	R	C	00005	R			

ENTRY POINTS

UNIT	SECTION	3

SUBROUTINES CALLED

SIN	SECTION	4	COS	SECTION	5	SQRT	SECTION	6
SYSLOC	SECTION	7						

EFN IFN CORRESPONDENCE

EFN	IFN	LOCATION	EFN	IFN	LOCATION	EFN	IFN	LOCATION

DECK LENGTH IN OCTAL IS 00255.

Subroutine PREDIK

Purpose: PREDIK is designed to compute a correction to the position and velocity vectors at a specified lead time to produce agreement between a set of 9 observations (acquired at 3 epoch) and the corresponding computed values by a weighted least squares process.

Deck Name: PRED

Calling Sequence: CALL PREDIK (RAD, VEL, T, ØBS, SIGMA2, CØRR, RTRAK, X, Y, Z)

Input/Output:

I/O	FØRTRAN Name	Math Name	Common/ Argument	Dimension	Description
I	RAD	$\vec{r}_i$	ARG	4 x 3	Arrays of position and velocity vectors at times corresponding to T_1, T_2, T_3, and T_4. These data are expressed in the true equator of date frame of reference and are assumed to be expressed in the units of ft and ft/sec.
	VEL	$\vec{v}_i$	ARG	4 x 3	
I	T	t_i	ARG	5	An array of times corresponding to the initial epoch (or first $\vec{r}$, $\vec{v}$), the three observations and the epoch at which the correction to $\vec{r}$, $\vec{v}$ will be applied. These times are expressed in seconds and can be referenced to any arbitrary epoch.
I	ØBS	Y	ARG	9	The ordered set of observations (observed minus computed residuals). This vector is in the order of range-rate, azimuth elevation, range-rate... etc. Units are ft/sec and radians.

I/O	FØRTRAN Name	Math Name	Common/ Argument	Dimension	Description
I	SIGMA2	$\vec{W}$	ARG	9	The weights for the 9 observations. This vector must be ordered in the same fashion as is the vector $\vec{Y}$.
Ø	CØRR	$\vec{X}(T)$	ARG	6	The estimate of the state vector at the time T_5 is obtained by a weighted least-squares process. Units are ft and ft/sec.
I	RTRAK X, Y, Z	$\vec{r}_T$ $\hat{U}, \hat{E}, \hat{N}$	ARG	3 x 3	Arrays of tracking station position (and the corresponding up, east, north unit vectors) for the times of the three sets of observations. (T_2, T_3, T_4) these data are assumed to be measured in feet.

Subroutines Required: ØBSERV (computes $[\partial \vec{Y} / \partial \vec{X}]$)

TRANS (computes $[\partial \vec{X}_i / \partial \vec{X}_o]$)

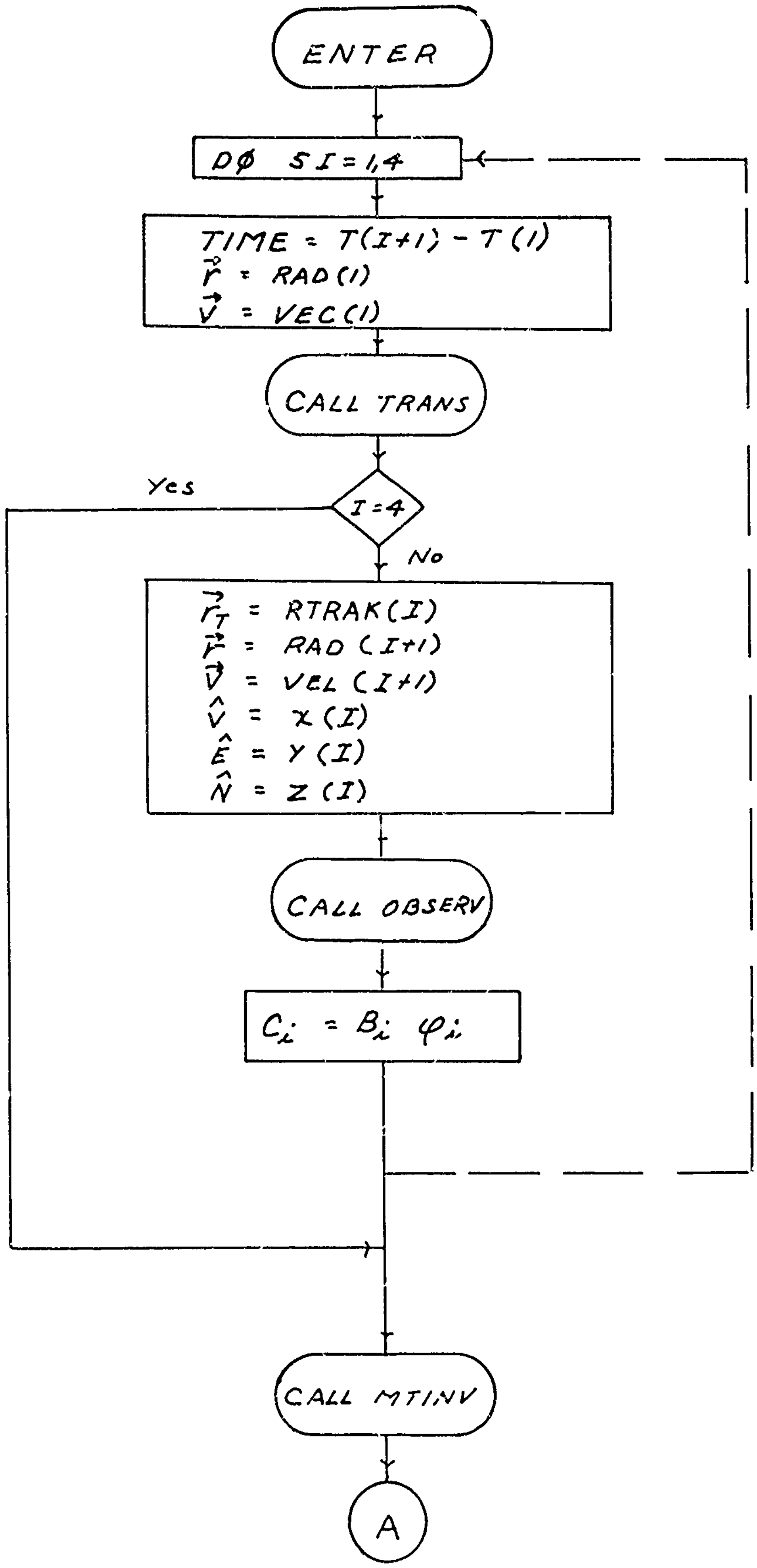
MATMPY (matrix multiplication)

MTINV (matrix inverse)

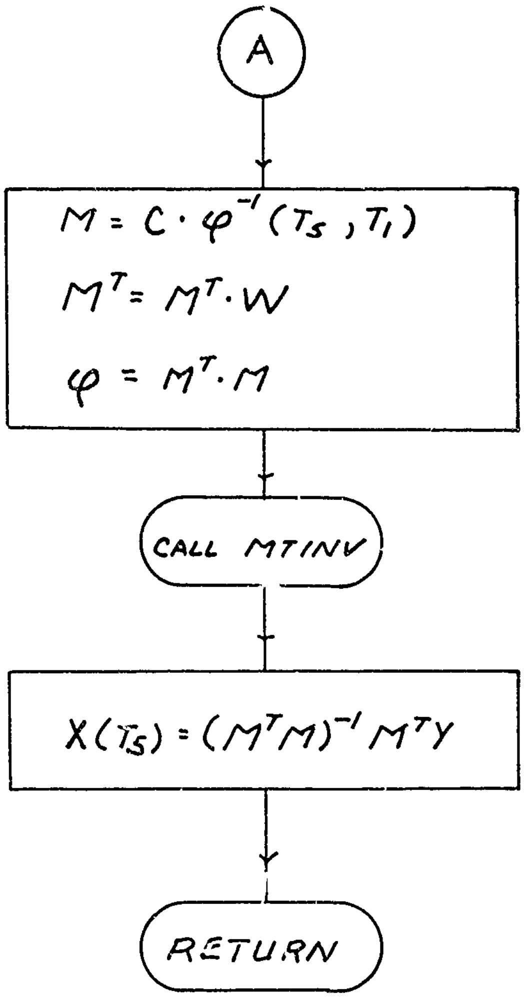
Functions Required: None

Approximate Deck Length: 01071_8

SUBROUTINE PREDIK



SUBROUTINE PREDIK (cont.)



Development of Equations :

The routine will be constructed to compute a weighted, least-squares correction to the computed position and velocity at a desired epoch based on a series of observed minus computed residuals recorded at a specified time prior to the epoch of the estimate. This objective will be accomplished by adopting a linear model which relates position errors at various epochs on the same trajectory (see TRANS). Thus, the errors in position and velocity at the times of the observations can be related to the errors at some standard epoch, by

$$\vec{X}_i = \varphi(t_i, t_0)\vec{X}_0$$

where

$$\varphi(t_i, t_o) = \frac{\partial \vec{x}_i}{\partial \vec{x}_o}$$

$$x = \begin{Bmatrix} \delta\vec{r} \\ \delta\vec{v} \end{Bmatrix}$$

t_i, t_o = the epochs of observation and reference, respectively.

Further, the errors in the observations can be expressed as linear functions of the error vector (X) (assuming that X never becomes large). This step is accomplished as follows:

$\vec{Y}_i$ = M vector of observed/computed residuals

$= B_i \vec{X}_i$

where

$$B_i = \frac{\partial \vec{Y}_i}{\partial x_i} = M \times 6 \text{ matrix}$$

Thus,

$$\vec{Y}_i = B_i \quad (t_i, t_o) \quad \vec{X}_o$$

Now the total set of observations can be expressed as

$$\vec{y} = \begin{Bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{Bmatrix} = \begin{bmatrix} B_1 \varphi_1 \\ B_2 \varphi_2 \\ \vdots \\ B_n \varphi_n \end{bmatrix} \vec{x}_o = C \vec{X}_o$$

where

$\vec{Y}$ = mn-vector

C = mn by 6 matrix

Finally, the errors at the time at which the correction is desired can be computed as

$$\vec{x}(T) = \varphi(T, t_0)\, \vec{x}(t_0)$$

or

$$\vec{y} = C\, \varphi^{-1}(T, t_0)\, \vec{x}(T)$$

$$\equiv M\, \vec{x}\,(T)$$

The problem thus reduces itself to the derivation of a computational alogrithm which will construct an "optimum estimate" of $\vec{X}(T)$ for the case where $mn > 6$.

Assume that the vector $\vec{Y}$ is now contaminated with noise as:

$$\vec{Y} = M\vec{X}(T) + \eta$$

or

$$\eta = \vec{Y} - M\,\vec{X}\,(T)$$

Further, construct the comparison function F $\left(F = \sum_{i=1}^{mn} w_i \eta_i^2\right)$ which is desired to be as small as possible.

$$F = \eta^T W \eta$$

where

W = diagonal matrix at weights

$$= \begin{bmatrix} \frac{1}{\sigma_1^2} & & 0 \\ & \ddots & \\ 0 & & \frac{1}{\sigma_{mn}^2} \end{bmatrix}$$

Now differentiate F with respect to X

$$\Delta F = -\Delta\vec{x}^T(T)\, M^T W(\vec{y} - M\vec{x}(T)) - (\vec{y} - M\vec{x}(T))^T W M \Delta\vec{x}\,(T)$$

$$= -\left[(M^T W\vec{y} - M^T W M\, \vec{x}\,(T))\, \Delta\vec{x}\,(t)\right]^T - \left[(M^T W\vec{y} - M^T W M\, \vec{x}(T))\, \Delta\vec{x}\,(t)\right]$$

Thus, if F is to be a minimum (i.e., $\Delta F = 0$), the function

$$M^T W \vec{Y} - M^T W M \vec{X}(T) = 0$$

and $\vec{X}(T)$ may be obtained as:

$$\hat{X}(T) = (M^T W M)^{-1} M^T W Y$$

It is important to note that since M is dimensioned mn by 6, neither it nor its transpose is invertible. Thus, the equation cannot be further simplified.

The actual problem will be a specific case of this analysis in that only a slightly over-determined set of equations will be processed. That is, only a slight amount of smoothing will be employed. In this case it is assumed that the following data are available.

Tracking Station

Time	$\vec{r}, \vec{v}$	$\vec{r}_T$	Up, East, North	Weights	Observations (0-C)
T_1	$\vec{r}_1, \vec{v}_1$				
T_2	$\vec{r}_2, \vec{v}_2$	$\vec{r}_{T1}$	$\hat{x}_1\ \hat{y}_1\ \hat{z}_1$	$\vec{W}_1$	$\vec{Y}_1$
T_3	$\vec{r}_3, \vec{v}_3$	$\vec{r}_{T2}$	$\hat{x}_2\ \hat{y}_2\ \hat{z}_2$	$\vec{W}_2$	$\vec{Y}_2$
T_4	$\vec{r}_4, \vec{v}_4$	$\vec{r}_{T2}$	$\hat{x}_3\ \hat{y}_3\ \hat{z}_3$	$\vec{W}_3$	$\vec{Y}_3$
T_5					

where

$$\vec{Y}_i = \begin{Bmatrix} \Delta \dot{R} \\ \Delta A \\ \Delta E \end{Bmatrix} \begin{matrix} \text{range rate} \\ \text{azimuth} \\ \text{elevation} \end{matrix}$$

$$\vec{\omega}_i = \begin{Bmatrix} \sigma^2_{\Delta \dot{R}} \\ \sigma^2_{\Delta A} \\ \sigma^2_{\Delta E} \end{Bmatrix} \begin{matrix} \text{variance in range-rate for ith observation} \\ \text{variance in azimuth for ith observation} \\ \text{variance in elevation for its observation} \end{matrix}$$

```
      SUBRØUTINE PREDIK(RAD,VEL,T,ØBS,SIGMA2,CØRR,                      PRED0010
     1                  RTRAK,X,Y,Z    )                                PRED0005
C                                                                       PRED0020
C                                                                       PRED0030
C     PREDIC IS DESIGNED TØ ACCEPT THREE SIGHTINGS ØF A SATELLITE       PRED0040
C              CØNTAINING RANGE-RATE , AZIMUTH , AND ELEVATIØN          PRED0050
C              INFØRMATIØN AND BY A WEIGHTED LEAST SQUARES PRØCESS      PRED0060
C              CØMPUTE A DIFFERENTIAL CØRRECTIØN TØ THE PØSITIØN AND    PRED0070
C              VELØCITY VECTØRS AT A TIME SLIGHTLY IN THE FUTURE .      PRED0080
C              THIS PRØCESS WILL ASSURE CØNSISTENTLY GØØD TRACKING DATA.PRED0090
C     RAD (VEL) IS AN ARRAY ØF PØSITIØN ( VELØCITY ) VECTØRS FØR THE    PRED0100
C              TIMES (T ALSØ AN ARRAY ) T1,T2,T3,AND T4 . THE           PRED0110
C              ØBSERVED MINUS CØMPUTED RESIDUALS (ØBS) ARE AVAILABLE.   PRED0120
C              AT THE THREE TIMES  T2,T3,T4                             PRED0125
C     SIGMA IS AN ARRAY CØNTAINING  THE VARIANCES IN THE THREE TYPES    PRED0126
C              ØF DATA AT THE THREE ØBSERVATIØN TIMES (T2,T3,T4)        PRED0127
C     ØBS FØR THIS RØUTINE IS ASSUMED TØ BE AN ARRAY ØF THREE SEPARATE  PRED0130
C              SETS ØF RESIDUALS ØRDERED AS FØLLØWS  **  RANGE-RATE,    PRED0140
C              AZIMUTH,ELEVATIØN,RANGE-RATE, ... ETC                    PRED0150
C     CØRR  IS THE PREDICTED CØRRECTIØN TØ THE PØSITIØN AND VELØCITY    PRED0160
C              VECTØRS AT THE TIME T5 ( THE T ARRAY HAS ITS LAST        PRED0170
C              ELEMENT = T5) .THIS ESTIMATE IS A WEIGHTED LEAST SQUARES PRED0180
C              PREDICTIØN DESIGNED TØ ADJUST THE CØMPUTED TRAJECTØRY    PRED0190
C              TØ AGREE WITH THE ØBSERVATIØNS                           PRED0200
C     THE REMAINING ARGUMENTS ARE REQUIRED FØR INPUT INTØ SUBRØUTINE    PRED0201
C              ØBSERV . THESE DATA ARE  * *                             PRED0202
C                   RTRAK = 3*3 ARRAY ØF STATIØN PØSITIØNS( T1,T2,T3 )  PRED0203
C                   X,Y,Z = UP,EAST,NØRTH UNIT VECTØRS FØR EACH PØSITIØNPRED0204
C                                                                       PRED0210
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * PRED0220
C                                                                       PRED0230
      DIMENSIØN RAD(4,3),T(5),R(3),V(3),PHI(6,6),A(3,6),BX(3,6),B(9,6), PRED0240
     1          PHINV(6,6),CAPM(9,6),CAPMT(6,9),ØBS(9),CØRR(6),VEL(4,3),PRED0250
     2          SIGMA2(9),RTRAK(3,3),X(3,3),Y(3,3),Z(3,3),              PRED0260
     3          RT(3),XX(3),YY(3),ZZ(3)                                 PRED0265
C                                                                       PRED0270
```

```
      PRED       -  EFN   SOURCE STATEMENT  -  IFN(S)  -

C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * PRED0280
C                                                                     PRED0290
C                                                                     PRED0300
C     COMPUTE THE MATRIX M      * * * * * * * * * * * * * * * * * * * * * PRED0310
C                                                                     PRED0320
      DO 5 I=1,4                                                      PRED0330
      TIME = T(I+1)-T(1)                                              PRED0340
      IF (TIME .LE. 1.E-6) TIME = 0.                                  PRED0345
      DO 10 J=1,3                                                     PRED0350
      R(J) = RAD(1,J)                                                 PRED0360
   10 V(J) = VEL(1,J)                                                 PRED0370
      CALL TRANS( R,V,TIME,PHI )                                      PRED0380    16
      IF(I-4) 15,20,20                                                PRED0390
   15 CONTINUE                                                        PRED0400
      DO 16 K=1,3                                                     PRED0401
      II    = I + 1                                                   PRED0401
      RT(K) = RTRAK(I,K)                                              PRED0402
      R(K)  = RAD(II,K)                                               PRED0402
      V(K)  = VEL(II,K)                                               PRED0402
      XX(K) = X(I,K)                                                  PRED0403
      YY(K) = Y(I,K)                                                  PRED0404
   16 ZZ(K) = Z(I,K)                                                  PRED0405
      CALL OBSERV( R,V,A,RT,XX,YY,ZZ )                                PRED0406    37
      CALL MATMPY( A,3,6,PHI,6,6,BX )                                 PRED0410    39
      IK = 3*I - 3                                                    PRED0420
      DO 25 J=1,3                                                     PRED0430
      DO 25 K=1,6                                                     PRED0440
      IJ = IK + J                                                     PRED0450
   25 B(IJ,K) = BX(J,K)                                               PRED0460
    5 CONTINUE                                                        PRED0470
   20 CONTINUE                                                        PRED0475
      CALL MTINV(PHI,PHINV,6 )                                        PRED0480    55
      CALL MATMPY( B,9,6,PHINV,6,6,CAPM )                             PRED0490
C                                                                     PRED0500
C     COMPUTE LEAST SQUARES CORRECTION TO R AND V AT T5 * * * * * * * * PRED0510
C                                                                     PRED0520    57
      DO 50 I=1,6                                                     PRED0530
```

```
      DO 50 J=1,9                                              PRED0540
      CAPMT(I,J) = CAPM(J,I)                                   PRED0550
      VARY = SIGMA2(J)                                         PRED0560
   50 CAPMT(I,J) = CAPMT(I,J) / VARY                           PRED0570
      CALL MATMPY ( CAPMT,6,9,CAPM,9,6,PHI )                   PRED0580   74
      CALL MTINV( PHI,PHINV,6 )                                PRED0590   76
      CALL MATMPY ( PHINV,6,6,CAPMT,6,9,B )                    PRED0600   78
      CALL MATMPY ( B,6,9,OBS,9,1,CORR )                       PRED0610
C                                                              PRED0620
C                                                              PRED0630   80
      RETURN                                                   PRED0640
      END                                                      PRED0650
```

SUBROUTINE PREDIK

DIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
R	00001	R	V	00004	R	PHI	00007	R
A	00053	R	BX	00075	R	B	00117	R
PHINV	00205	R	CAPM	00251	R	CAPMT	00337	R
RT	00425	R	XX	00430	R	YY	00433	R
ZZ	00436	R						

UNDIMENSIONED PROGRAM VARIABLES

SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE	SYMBOL	LOCATION	TYPE
I	00441	I	TIME	00442	R	J	00443	I
II	00444	I	IK	00445	I	IJ	00446	I
VARY	00447	R						

ENTRY POINTS

PREDIK SECTION 3

SUBROUTINES CALLED

TRANS	SECTION	4	OBSERV	SECTION	5	MATMPY	SECTION	6
MTINV	SECTION	7	SYSLOC	SECTION	8			

EFN IFN CORRESPONDENCE

EFN	IFN	LOCATION	EFN	IFN	LOCATION	EFN	IFN	LOCATION
5	51A	00651	10	12A	00501	15	19A	00521
20	54A	00653	16	33A	00563	25	46A	00636

PRED STØRAGE MAP

```
50            68A         00716
 DECK LENGTH IN ØCTAL IS     01071.
```

Subroutine ØBSERV

Purpose: ØBSERV computes the 3 by 6 matrix of partial derivatives of the observables with respect to the state for the case where range-rate, azimuth and elevation are acquired.

Deck Name: ØBSN

Calling Sequence: CALL ØBSERV (RVEC, VVEC, ØBSN, RTRAK, X, Y, Z)

Input/Output:

I/O	FØRTRAN Name	Math Name	Dimension	Common/ Argument	Definition
I	RVEC	$\vec{r}$	3	ARG	The position and velocity vectors for the satellite on the estimated trajectory in the true equator of date frame of reference. Units are ft and ft/sec.
	VVEC	$\vec{v}$	3	ARG	
Ø	ØBSN	B	3 x 6	ARG	The matrix of partials of range-rate, azimuth and elevation with respect to errors in position and velocity (state). Units are ft/sec per (ft, ft/sec) and rad per (ft, ft/sec).
I	RTRAK	$\vec{r}_T$	3	ARG	The position vector for the tracking station at the time of the observation being considered (ft).
I	X,Y,Z	V,E,N	3,3,3	ARG	The up, east, north unit vectors at the tracking station.

Subroutines Required:	CRØSS (crossproduct)
Functions Required:	AMAG (magnitude of a vector) SQRT (square root) DØT (dot product)
Approximate Deck Length:	00335_8

SUBROUTINE OBSERV

ENTER

$$\vec{\rho} = \vec{r} - \vec{r}_T$$

$$\rho = |\vec{\rho}|$$

$$\hat{\rho} = \vec{\rho}/\rho$$

$$\vec{V}_T = \vec{\omega} \times \vec{r}_T$$

$$\vec{V}_r = \vec{V} - \vec{V}_T$$

Partials of range-rate

$$\dot{\rho} = \hat{\rho} \cdot \vec{V}_r$$

$$\frac{\partial \dot{\rho}}{\partial \vec{r}} = \frac{\vec{V}_r}{\rho} - \frac{\dot{\rho}\vec{\rho}}{\rho^2}$$

$$\frac{\partial \dot{\rho}}{\partial \vec{V}} = \hat{\rho}$$

Partials of Azimuth

$$f = \vec{\rho} \cdot \hat{E}$$

$$g = \vec{\rho} \cdot \hat{N}$$

$$s^2 = f^2 + g^2$$

$$\frac{\partial A}{\partial \vec{r}} = (\hat{E} g - f \hat{N})/s^2$$

$$\frac{\partial A}{\partial \vec{V}} = 0$$

A

SUBROUTINE OBSERV (cont.)

A

Partials of Elevation

$$f = \vec{\rho} \cdot \hat{v}$$

$$\frac{\partial E}{\partial \vec{r}} = \left(\hat{v} - \frac{f \vec{\rho}}{\rho^2} \right) / s$$

$$\frac{\partial E}{\partial \vec{V}} = 0$$

RETURN

Formulation:

ØBSERV is constructed to define the partial derivatives of the observables (i.e., range-rate, azimuth and elevation) with respect to the state vector (i.e., $\Delta\bar{r}$, $\Delta\bar{v}$). This information is to be presented in the form of the 3 by 6 matrix illustrated in the following equation:

$$\begin{Bmatrix} \Delta \dot{R} \\ \Delta A \\ \Delta E\ell \end{Bmatrix}_t = B(t)\,\delta\chi(t)$$

The matrix B(t) will be constructed from the following equations

$$\dot{R} = (\hat{r}_r \cdot \hat{V}_r)$$
$$A = \tan^{-1}\left(\frac{\vec{r}_r \cdot \hat{E}}{\vec{r}_r \cdot \hat{N}}\right)$$
$$E\ell = \sin^{-1}(\vec{r}_r \cdot \hat{U})$$
$$\vec{X} = \vec{r} - \vec{r}_n$$
$$\vec{r}_r = \vec{r} - \vec{r}_T$$
$$\hat{r}_r = \vec{r}_r / R$$
$$V_r = \vec{V} - \vec{V}_r$$

where:

$\dot{R}$ = range rate

Az = azimuth

EL = elevation

$\hat{U}, \hat{E}, \hat{N}$ = up, east, north unit vectors at tracking station

$\vec{r}$ = vehicle's position in equatorial frame of date

$\vec{r}_n$ = nominal position on reference orbit

$\vec{r}_T$ = tracking station's position vector

when it is noted that for the purpose of differentiation, the nominal position vector and the tracking station position vector are constant, i.e.,

$$d\vec{X} = d\vec{r}_r$$

This set of operations has been performed, and the results of the analysis are presented below:

1. Partials of range-rate

$$\dot{R} = \frac{x_r}{R}\dot{x}_r + \frac{y_r}{R}\dot{y}_r + \frac{z_r}{R}\dot{z}_r$$

$$\frac{\partial \dot{R}}{\partial \vec{x}} = \left(\frac{\partial \dot{R}}{\partial \vec{r}}, \frac{\partial \dot{R}}{\partial \vec{V}}\right) = \left(\frac{\dot{x}_r}{R} - \frac{\dot{R}x_r}{R^2}, \frac{\dot{y}_r}{R} - \frac{\dot{R}x_r}{R^2}, \frac{\dot{z}_r}{R} - \frac{\dot{R}z_r}{R^2}, \frac{x_r}{R}, \frac{y_r}{R}, \frac{z_r}{R}\right)$$

2. Partials of azimuth

$$S^2 = (\vec{r}_r \cdot \hat{E})^2 + (\vec{r}_r \cdot \hat{N})^2$$

$$\frac{\partial A}{\partial X} = \left(\frac{\partial A}{\partial \vec{r}}, \frac{\partial A}{\partial \vec{V}}\right) = \left[\frac{u_1}{S} - x_r\left(\frac{\hat{U}\cdot\vec{r}_r}{R^2 S}\right), E_2\left(\frac{\hat{N}\cdot\vec{r}_r}{S^2}\right) - N_2\left(\frac{\hat{E}\cdot\vec{r}_r}{S^2}\right),\right.$$

$$\left. E_3\left(\frac{\hat{N}\cdot\vec{r}_r}{S^2}\right) - N_3\left(\frac{\hat{E}\cdot\vec{r}_r}{S^2}\right), 0, 0, 0\right]$$

3. Partials of elevation

$$\frac{\partial E\ell}{\partial \vec{X}} = \left(\frac{\partial E\ell}{\partial \vec{r}}, \frac{\partial E\ell}{\partial \vec{V}}\right) = \left[\frac{U_1}{S} - x_r\left(\frac{\hat{U}\cdot\vec{r}_r}{R^2 S}\right), \frac{U_2}{S} - y_r\left(\frac{\hat{U}\cdot\vec{r}_r}{R^2 S}\right),\right.$$

$$\left.\frac{U_3}{S} - z_r\left(\frac{\hat{U}\cdot\vec{r}_r}{R^2 S}\right), 0, 0, 0\right]$$

```
      SUBRØUTINE ØBSERV( RVEC,VVEC,ØBSN,RTRAK,X,Y,Z )                   ØBSN0010
C                                                                       ØBSN0020
C     THIS RØUTINE EVALUATES THE MATRIX ØF THE PARTIALS ØF THE          ØBSN0030
C              ØBSERVATIØNS WITH RESPECT TØ THE STATE .THIS MATRIX      ØBSN0040
C              WILL BE UTILIZED IN A WEIGHTED LEAST SQUARES REDUCTIØN   ØBSN0050
C              ØF RANGE-RATE,AZIMUTH, AND ELEVATIØN DATA                ØBSN0060
C     RVEC IS THE VECTØR PØSITIØN IN THE FRAME ØF DATE                  ØBSN0150
C     VVEC IS THE VECTØR VELØCITY IN THE FRAME ØF DATE                  ØBSN0160
C     RTRAK IS THE PØSITIØN VECTØR ØF THE TRACKING STATIØN IN THE       ØBSN0170
C              TRUE EQUATØR ØF DATE FRAME                               ØBSN0180
C     X,Y,Z ARE ZENITH,EAST,AND NØRTH UNIT VECTØRS AT THE STATIØN       ØBSN0185
C     ØBSN IS THE 3*6 MATRIX ØF PARTIALS ØF THE ØBSERVATIØNS WITH       ØBSN0190
C              RESPECT TØ THE STATE VECTØR ( RDØT,AZIMUTH,ELEVATIØN )   ØBSN0200
C                                                                       ØBSN0214
C                                                                       ØBSN0216
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ØBSN0220
C                                                                       ØBSN0230
      DIMENSIØN RVEC(3),VVEC(3),RHØ(3),RTRAK(3),ØBSN(3,6),              ØBSN0240
     1UNIT(3),X(3),Y(3),Z(3),XN(3),VTRAK(3),VREL(3)
      DATA      ØMEGA / .72921156E-04/                                  ØBSN0270
C                                                                       ØBSN0290
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ØBSN0295
C                                                                       ØBSN0300
C     THE RELATIVE PØSITIØN VECTØR                                      ØBSN0310
      DØ 1 I=1,3                                                        ØBSN0340
    1 RHØ(I) = RVEC(I) - RTRAK(I)                                       ØBSN0350
      RHØM = AMAG(RHØ)                                                  ØBSN0360     11
      DØ 2 I=1,3                                                        ØBSN0370
    2 UNIT(I)=RHØ(I)/ RHØM                                              ØBSN0380
C                                                                       ØBSN0390
C     THE PARTIALS ØF RANGE-RATE                                        ØBSN0400
      XN(1) = 0.                                                        ØBSN0480
      XN(2) = 0.                                                        ØBSN0490
      XN(3) = ØMEGA                                                     ØBSN0500
      CALL CRØSS( XN,RTRAK,VTRAK)                                       ØBSN0510     20
      DØ 11 I=1,3                                                       ØBSN0520
```

```
   11 VREL(I) = VVEC(I) - VTRAK(I)                                         ØBSN0530
      RHØDØT = DØT(VREL,UNIT)                                              ØBSN0540     31
      DØ 12 I=1,3                                                          ØBSN0550
      ØBSN(1,I)=VREL(I)/ RHØM - RHØDØT*RHØ(I)/( RHØM*RHØM )               ØBSN0560
      K= I+3                                                               ØBSN0565
   12 ØBSN(1,K)=UNIT(I)                                                    ØBSN0570
C                                                                          ØBSN0580
C     THE PARTIALS ØF AZIMUTH AND ELEVATIØN                                ØBSN0590
      F = DØT(RHØ,Y)                                                       ØBSN0610     43
      G = DØT(RHØ,Z)                                                       ØBSN0620     44
      S2=  F*F + G*G                                                       ØBSN0630
      DØ 21 I=1,3                                                          ØBSN0640
      ØBSN(2,I)=(Y(I)*G - F*Z(I))/S2                                       ØBSN0650
      K= I+3                                                               ØBSN0655
   21 ØBSN(2,K)=0.                                                         ØBSN0660
      S =SQRT(S2)                                                          ØBSN0670     55
      F = DØT(X,RHØ )                                                      ØBSN0680     56
      DØ 22 I=1,3                                                          ØBSN0690
      ØBSN(3,I)=(X(I)    - F*RHØ(I)/(RHØM*RHØM))/ S                        ØBSN0700
      K= I+3                                                               ØBSN0705
   22 ØBSN(3,K)=0.                                                         ØBSN0710
      RETURN                                                               ØBSN1120
      END                                                                  ØBSN1130
```

STØRAGE MAP

SUBRØUTINE ØBSERV

DIMENSIØNED PRØGRAM VARIABLES

SYMBØL	LØCATIØN	TYPE	SYMBØL	LØCATIØN	TYPE	SYMBØL	LØCATIØN	TYPE
RHØ	00001	R	UNIT	00004	R	XN	00007	R
VTRAK	00012	R	VREL	00015	R			

UNDIMENSIØNED PRØGRAM VARIABLES

SYMBØL	LØCATIØN	TYPE	SYMBØL	LØCATIØN	TYPE	SYMBØL	LØCATIØN	TYPE
I	00020	I	RHØM	00021	R	ØMEGA	00022	R
RHØDØT	00023	R	K	00024	I	F	00025	R
G	00026	R	S2	00027	R	S	00030	R

ENTRY PØINTS

ØBSERV SECTIØN 3

SUBRØUTINES CALLED

AMAG	SECTIØN	4	CRØSS	SECTIØN	5	DØT	SECTIØN	6
SQRT	SECTIØN	7	SYSLØC	SECTIØN	8			

EFN IFN CØRRESPØNDENCE

EFN	IFN	LØCATIØN	EFN	IFN	LØCATIØN	EFN	IFN	LØCATIØN
1	5A	00041	2	15A	00054	11	25A	00074
12	38A	00132	21	51A	00206	22	63A	00254

DECK LENGTH IN ØCTAL IS 00355.

INPUT DATA

All input data is read in under a floating point format. The first card contains the initial position and velocity vectors (see Figure 1). The first two fields of the second card refers to the initial time. The first field contains the whole number of julian days past 0^h 1 January 1950 (JD 2433282.5), and the second field contains the fractional part of the day. The third and fourth fields contain the step size and the final elapsed time (in seconds). The fifth field contains the W/C_DA in pounds per square foot, and the last field contains the number of tracking stations considered (input as a floating point number). The third card contains data describing the first tracking station. The first half of the first field (first six columns) holds the station name (6 letters maximum), and the second half is blank. The next four fields contain the longitude, latitude, altitude, and horizon correction for the station. The last field is blank. A maximum of ten tracking stations may be active; data for each active station must be input on a separate card following the first station data card.

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.______ PROGRAMMER______ DATE______ PAGE____of____ JOB NO.______

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1			x component of initial position vector
13			y
25			z
37			x component of initial velocity vector
49		73 80	y
61		D A T A 0 0 0 1	z
1			initial { whole number of days past 0^h 1 Jan. 1950
13			time { fractional part of a day
25			step size in seconds
37			final elapsed time in seconds
49		73 80	W/C_DA in pounds 1 square foot
61		D A T A 0 0 0 2	number of tracking stations (max. = 10.)
1			name of tracking station (6 letters max)
13			longitude (deg, + east)
25			latitude (deg, + north)
37			altitude over $\frac{1}{298.3}$ spheroid (ft)
49		73 80	horizon corrections (deg)
61		D A T A 0 0 0 3	
1			
13			
25			Tracking station data
37			one card for each station
49		73 80	
61			

FIGURE 1. INPUT FORMAT

OUTPUT DATA

Immediately after reading the input data, a record of the input data is printed out for reference. The initial osculating elements are also printed out.

Beyond this, output consists of the position and velocity vectors at each step and tracking data at any step when the satellite is viewed by a tracking station.

To illustrate the output format and to assist in the checkout of any program developed from this document, several pages of sample output have been included. The initial conditions nave been printed out; note that the step size was four minutes.

INPUT DATA

```
X (FT)            Y                 Z                 XDOT (FPS)        YDOT              ZDOT
TIME (WH DAYS)    TIME (FR DAYS)    D TIME (SEC)      FNL TIME (SEC)    WCDA (LB/FT2)     NO OF STATIONS

-0.19409264E 08   -0.95740097E 07   0.12411661E 08    -0.90041042E 04   -0.89566827E 04   -0.19930562E 05
0.55880000E 04    0.00000000E-38    0.24000000E 03    0.60000000E 11    0.10000000E 02                  1
```

SID 65-1203-3

TRACKING STATION DATA (DEG,FT)

NAME	LONG (+ EAST)	LAT (+ NORTH)	ALTITUDE	HORIZ CORR
FLOYD	0.28465960E 03	0.43197136E 02	0.58850000E 03	0.00000000E-38

```
OSCUL OUTPUT - A,MU,NU,P,Q,TCAP
0.24699224E 08   0.22241512E-01   0.10200773E-01   0.51229944E 00   0.84584028E 00   -0.32223468E 04

TIME (SEC) =      0.24000000E 03
R (FEET) =     -0.21049555E 08   -0.11457374E 08    0.73481839E 07
R (KM  ) =     -0.64159045E 04   -0.34922076E 04    0.22397264E 04
V (KPS)  =     -0.14068481E 01   -0.20347517E 01   -0.67300020E 01

TIME (SEC) =      0.48000000E 03
R (FEET) =     -0.21610390E 08   -0.12753343E 08    0.19061293E 07
R (KM  ) =     -0.65868470E 04   -0.38872191E 04    0.58098821E 03
V (KPS)  =     -0.13657171E-01   -0.12441241E 01   -0.70331835E 01

TIME (SEC) =      0.72000000E 03
R (FEET) =     -0.21075021E 08   -0.13402481E 08   -0.36333531E 07
R (KM  ) =     -0.64236665E 04   -0.40850763E 04   -0.11074460E 04
V (KPS)  =      0.13663849E 01   -0.39852294E 00   -0.69773915E 01

TIME (SEC) =      0.96000000E 03
```

```
R (FEET) =   -0.19479756E 08  -0.13377639E 08  -0.89900012E 07
R (KM  ) =   -0.59374295E 04  -0.40775044E 04  -0.27401524E 04
V (KPS)  =    0.26678676E 01   0.46088592E 00  -0.65714794E 01

TIME (SEC) =   0.12000000E 04
R (FEET) =   -0.16910507E 08  -0.12683942E 08  -0.13896293E 08
R (KM  ) =   -0.51543225E 04  -0.38660656E 04  -0.42355901E 04
V (KPS)  =    0.38306497E 01   0.12936289E 01  -0.58385909E 01

TIME (SEC) =   0.14400000E 04
R (FEET) =   -0.13497991E 08  -0.11357745E 08  -0.18108115E 08
R (KM  ) =   -0.41141876E 04  -0.34618407E 04  -0.55193536E 04
V (KPS)  =    0.48013424E 01   0.20610934E 01  -0.48146073E 01

TIME (SEC) =   0.16800000E 04
R (FEET) =   -0.94118882E 07  -0.94647520E 07  -0.21414204E 08
R (KM  ) =   -0.28687435E 04  -0.28848564E 04  -0.65270494E 04
V (KPS)  =    0.55345005E 01   0.27274947E 01  -0.35467376E 01

TIME (SEC) =   0.19200000E 04
R (FEET) =   -0.48541667E 07  -0.70974289E 07  -0.23644513E 08
R (KM  ) =   -0.14795500E 04  -0.21632963E 04  -0.72068476E 04
V (KPS)  =    0.59937323E 01   0.32607659E 01  -0.20922853E 01

TIME (SEC) =   0.21600000E 04
R (FEET) =   -0.51494801E 05  -0.43717253E 07  -0.24677677E 08
R (KM  ) =   -0.15695615E 02  -0.13325019E 04  -0.75217559E 04
V (KPS)  =    0.61529233E 01   0.36334991E 01  -0.51748664E 00

TIME (SEC) =   0.24000000E 04
R (FEET) =    0.47533439E 07  -0.14230109E 07  -0.24447539E 08
R (KM  ) =    0.14488192E 04  -0.43373371E 03  -0.74516100E 04
V (KPS)  =    0.59976838E 01   0.38240484E 01   0.11037768E 01

TIME (SEC) =   0.26400000E 04
R (FEET) =    0.93113432E 07   0.15989640E 07  -0.22948579E 08
```

```
R (KM  ) =     0.28380974E 04    0.48736423E 03   -0.69947270E 04
V (KPS)  =     0.55270281E 01    0.38178487E 01    0.26917222E 01

TIME (SEC) =     0.28800000E 04
R (FEET) =     0.13378561E 08    0.45362375E 07   -0.20239665E 08
R (KM  ) =     0.40777855E 04    0.13826452E 04   -0.61690499E 04
V (KPS)  =     0.47551363E 01    0.36089238E 01    0.41631885E 01

TIME (SEC) =     0.31200000E 04
R (FEET) =     0.16728785E 08    0.72300853E 07   -0.16445332E 08
R (KM  ) =     0.50989338E 04    0.22037300E 04   -0.50125372E 04
V (KPS)  =     0.37128639E 01    0.32014335E 01    0.54352734E 01

TIME (SEC) =     0.33600000E 04
R (FEET) =     0.19167034E 08    0.95295509E 07   -0.11753687E 08
R (KM  ) =     0.58421121E 04    0.29046071E 04   -0.35825238E 04
V (KPS)  =     0.24485267E 01    0.26109997E 01    0.64302018E 01

TIME (SEC) =     0.36000000E 04
R (FEET) =     0.20543137E 08    0.11300786E 08   -0.64100012E 07
R (KM  ) =     0.62615481E 04    0.34444797E 04   -0.19537684E 04
V (KPS)  =     0.10273258E 01    0.18654088E 01    0.70813360E 01

TIME (SEC) =     0.38400000E 04
R (FEET) =     0.20764093E 08    0.12436505E 08   -0.70541891E 06
R (KM  ) =     0.63288955E 04    0.37906468E 04   -0.21501168E 03
V (KPS)  =    -0.47116539E 00    0.10042386E 01    0.73397492E 01

TIME (SEC) =     0.40800000E 04
R (FEET) =     0.19803640E 08    0.12864617E 08    0.50393352E 07
R (KM  ) =     0.60361494E 04    0.39211353E 04    0.15359894E 04
V (KPS)  =    -0.19577876E 01    0.77034311E-01    0.71803505E 01

TIME (SEC) =     0.43200000E 04
R (FEET) =     0.17707282E 08    0.12554866E 08    0.10494513E 08
R (KM  ) =     0.53971794E 04    0.38267231E 04    0.31987274E 04
```

```
V (KPS)   =   -0.33406543E 01  -0.86008289E 00   0.66062236E 01

TIME (SEC) =    0.45600000E 04
R (FEET) =    0.14591423E 08   0.11522305E 08   0.15344225E 08
R (KM  ) =    0.44474656E 04   0.35119986E 04   0.46769197E 04
V (KPS)  =   -0.45331805E 01  -0.17490389E 01   0.56499594E 01

TIME (SEC) =    0.48000000E 04
R (FEET) =    0.10636130E 08   0.98268911E 07   0.19309138E 08
R (KM  ) =    0.32418923E 04   0.29952364E 04   0.58854252E 04
V (KPS)  =   -0.54619320E 01  -0.25349540E 01   0.43713723E 01

TIME (SEC) =    0.50400000E 04
R (FEET) =    0.60721227E 07   0.75690453E 07   0.22166108E 08
R (KM  ) =    0.18507830E 04   0.23070450E 04   0.67562297E 04
V (KPS)  =   -0.60728614E 01  -0.31708941E 01   0.28518928E 01

TIME (SEC) =    0.52800000E 04
R (FEET) =    0.11637062E 07   0.48818150E 07   0.23762379E 08
R (KM  ) =    0.35469766E 03   0.14879772E 04   0.72427730E 04
V (KPS)  =   -0.63349324E 01  -0.36214216E 01   0.11867892E 01

TIME (SEC) =    0.55200000E 04
R (FEET) =   -0.38099933E 07   0.19208423E 07   0.24023093E 08
R (KM  ) =   -0.11612860E 04   0.58547272E 03   0.73222388E 04
V (KPS)  =   -0.62409149E 01  -0.38645414E 01  -0.52322740E 00

TIME (SEC) =    0.57600000E 04
R (FEET) =   -0.85733182E 07  -0.11465204E 07   0.22952291E 08
R (KM  ) =   -0.26131474E 04  -0.34945941E 03   0.69958582E 04
V (KPS)  =   -0.58038093E 01  -0.38920954E 01  -0.21797125E 01

STATION  FLOYD OBSERVES VEHICLE AT    0.55880000E 04    0.66666663E-01 DAYS
RELATIVE POSITION =    0.54345854E 07  -0.72321770E 07   0.86945640E 07
RELATIVE VELOCITY =   -0.18604157E 05  -0.11747870E 05  -0.71512878E 04
R, RDOT, AZ, ELEV =    0.38244147E 04  -0.19025699E 01   0.20862587E 02   0.10154029E 01
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TIME (SEC) =       0.60000000E 04
R (FEET) =     -0.12870305E 08   -0.41518148E 07    0.20628391E 08
R (KM   ) =    -0.39228698E 04   -0.12654732E 04    0.62875337E 04
V (KPS)   =    -0.50636792E 01   -0.37089366E 01   -0.36927339E 01

STATION  FLOYD OBSERVES VEHICLE AT      0.55880000E 04   0.69444440E-01 DAYS
RELATIVE POSITION =    0.12419549E 07   -0.99913962E 07    0.63706647E 07
RELATIVE VELOCITY =   -0.16187292E 05   -0.11139345E 05   -0.12115269E 05
R, RDOT, AZ, ELEV =    0.36315461E 04    0.35844297E 00    0.47429680E 02    0.35749211E 01

TIME (SEC) =       0.62400000E 04
R (FEET) =     -0.16478010E 08   -0.69350347E 07    0.17195536E 08
R (KM   ) =    -0.50224973E 04   -0.21137986E 04    0.52411993E 04
V (KPS)   =    -0.40636412E 01   -0.33312989E 01   -0.49854186E 01

STATION  FLOYD OBSERVES VEHICLE AT      0.55880000E 04   0.72222218E-01 DAYS
RELATIVE POSITION =   -0.22657169E 07   -0.12526753E 08    0.29378092E 07
RELATIVE VELOCITY =   -0.12924402E 05   -0.98930815E 04   -0.16356360E 05
R, RDOT, AZ, ELEV =    0.39820895E 04    0.24533912E 01    0.72915060E 02    0.90474185E 00

TIME (SEC) =       0.64800000E 04
R (FEET) =     -0.19216532E 08   -0.93526960E 07    0.12852130E 08
R (KM   ) =    -0.58571989E 04   -0.28507017E 04    0.39173292E 04
V (KPS)   =    -0.28655926E 01   -0.27847216E 01   -0.59968542E 01

TIME (SEC) =       0.67200000E 04
R (FEET) =     -0.20955813E 08   -0.11284230E 08    0.78377377E 07
R (KM   ) =    -0.63873318E 04   -0.34394333E 04    0.23889424E 04
V (KPS)   =    -0.15360549E 01   -0.21017969E 01   -0.66835792E 01

TIME (SEC) =       0.69600000E 04
R (FEET) =     -0.21619398E 08   -0.12636674E 08    0.24192632E 07
R (KM   ) =    -0.65895924E 04   -0.38516583E 04    0.73739140E 03
V (KPS)   =    -0.14437917E 00   -0.13199323E 01   -0.70198928E 01
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TIME (SEC) =     0.72000000E 04
R (FEET)   =    -0.21185452E 08   -0.13347702E 08   -0.31228540E 07
R (KM   )  =    -0.64573258E 04   -0.40683797E 04   -0.95184589E 03
V (KPS)    =     0.12405191E 01   -0.47927105E 00   -0.69972599E 01

TIME (SEC) =     0.74400000E 04
R (FEET)   =    -0.19685418E 08   -0.13387106E 08   -0.85077872E 07
R (KM   )  =    -0.60001155E 04   -0.40803898E 04   -0.25931735E 04
V (KPS)    =     0.25528018E 01    0.37911194E 00   -0.66230949E 01

TIME (SEC) =     0.76800000E 04
R (FEET)   =    -0.17200750E 08   -0.12756932E 08   -0.13466377E 08
R (KM   )  =    -0.52427886E 04   -0.38883129E 04   -0.41045517E 04
V (KPS)    =     0.37317274E 01    0.12146997E 01   -0.59192442E 01

TIME (SEC) =     0.79200000E 04
R (FEET)   =    -0.13858234E 08   -0.11490542E 08   -0.17751911E 08
R (KM   )  =    -0.42239898E 04   -0.35023171E 04   -0.54107824E 04
V (KPS)    =     0.47231714E 01    0.19887212E 01   -0.49204339E 01

TIME (SEC) =     0.81600000E 04
R (FEET)   =    -0.98242617E 07   -0.96508150E 07   -0.21149662E 08
R (KM   )  =    -0.29944350E 04   -0.29415684E 04   -0.64464170E 04
V (KPS)    =     0.54808375E 01    0.26651292E 01   -0.36728534E 01

TIME (SEC) =     0.84000000E 04
R (FEET)   =    -0.52982051E 07   -0.73276393E 07   -0.23485385E 08
R (KM   )  =    -0.16148929E 04   -0.22334644E 04   -0.71583452E 04
V (KPS)    =     0.59673775E 01    0.32114962E 01   -0.22329083E 01

TIME (SEC) =     0.86400000E 04
R (FEET)   =    -0.50494313E 06   -0.46347027E 07   -0.24632851E 08
R (KM   )  =    -0.15390667E 03   -0.14126574E 04   -0.75080930E 04
V (KPS)    =     0.61556014E 01    0.35999468E 01   -0.66606633E 00
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TIME (SEC) =     0.88800000E 04
R (FEET) =     0.43136425E 07   -0.17055332E 07   -0.24520498E 08
R (KM  ) =     0.13147982E 04   -0.51984652E 03   -0.74738478E 04
V (KPS)  =     0.60299119E 01    0.38082430E 01    0.95440842E 00

TIME (SEC) =     0.91200000E 04
R (FEET) =     0.89034297E 07    0.13114375E 07   -0.23136981E 08
R (KM  ) =     0.27152894E 04    0.39972615E 03   -0.70521519E 04
V (KPS)  =     0.55879747E 01    0.38210880E 01    0.25491421E 01

TIME (SEC) =     0.93600000E 04
R (FEET) =     0.13034251E 08    0.42589392E 07   -0.20535124E 08
R (KM  ) =     0.39728398E 04    0.12981246E 04   -0.62591059E 04
V (KPS)  =     0.48424883E 01    0.36316215E 01    0.40351014E 01

TIME (SEC) =     0.96000000E 04
R (FEET) =     0.16462445E 08    0.69781619E 07   -0.16833481E 08
R (KM  ) =     0.50177532E 04    0.21269438E 04   -0.51308449E 04
V (KPS)  =     0.38227459E 01    0.32429779E 01    0.53291168E 01

TIME (SEC) =     0.98400000E 04
R (FEET) =     0.18994359E 08    0.93172299E 07   -0.12214560E 08
R (KM  ) =     0.57894807E 04    0.28398917E 04   -0.37229980E 04
V (KPS)  =     0.25755037E 01    0.26696427E 01    0.63526617E 01

TIME (SEC) =     0.10080000E 05
R (FEET) =     0.20474975E 08    0.11140454E 08   -0.69188659E 07
R (KM  ) =     0.62407725E 04    0.33956103E 04   -0.21088703E 04
V (KPS)  =     0.11645603E 01    0.19382351E 01    0.70377735E 01

TIME (SEC) =     0.10320000E 05
R (FEET) =     0.20805470E 08    0.12337820E 08   -0.12340324E 07
R (KM  ) =     0.63415074E 04    0.37605674E 04   -0.37613308E 03
V (KPS)  =    -0.33157147E 00    0.10872485E 01    0.73336259E 01

TIME (SEC) =     0.10560000E 05
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R (FEET) =	0.19953122E 08	0.12833734E 08	0.45210369E 07
R (KM) =	0.60817117E 04	0.39117221E 04	0.13780120E 04
V (KPS) =	-0.18242536E 01	0.16536724E 00	0.72127499E 01
TIME (SEC) =	0.10800000E 05		
R (FEET) =	0.17956817E 08	0.12593890E 08	0.10016437E 08
R (KM) =	0.54732379E 04	0.38386176E 04	0.30530101E 04
V (KPS) =	-0.32214399E 01	-0.77178980E 00	0.66755849E 01
TIME (SEC) =	0.11040000E 05		
R (FEET) =	0.14926746E 08	0.11629062E 08	0.14934029E 08
R (KM) =	0.45496723E 04	0.35445381E 04	0.45518921E 04
V (KPS) =	-0.44356549E 01	-0.16662006E 01	0.57521129E 01
TIME (SEC) =	0.11280000E 05		
R (FEET) =	0.11037723E 08	0.99950669E 07	0.18990274E 08
R (KM) =	0.33642979E 04	0.30464964E 04	0.57882354E 04
V (KPS) =	-0.53919312E 01	-0.24625702E 01	0.44998921E 01
TIME (SEC) =	0.11520000E 05		
R (FEET) =	0.65166233E 07	0.77886782E 07	0.21956254E 08
R (KM) =	0.19862668E 04	0.23739891E 04	0.66922661E 04
V (KPS) =	-0.60342388E 01	-0.31131477E 01	0.29987017E 01
TIME (SEC) =	0.11760000E 05		
R (FEET) =	0.16255858E 07	0.51400736E 07	0.23672415E 08
R (KM) =	0.49547854E 03	0.15666944E 04	0.72153521E 04
V (KPS) =	-0.63293642E 01	-0.35813987E 01	0.13428954E 01
TIME (SEC) =	0.12000000E 05		
R (FEET) =	-0.33567122E 07	0.22029552E 07	0.24056692E 08
R (KM) =	-0.10231259E 04	0.67146074E 03	0.73324797E 04
V (KPS) =	-0.62679428E 01	-0.38440960E 01	-0.36700176E 00
TIME (SEC) =	0.12240000E 05		
R (FEET) =	-0.81534576E 07	-0.85627353E 06	0.23106040E 08

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R (KM  ) =    -0.24851739E 04   -0.26099369E 03    0.70427209E 04
V (KPS)  =    -0.58630610E 01   -0.38918375E 01   -0.20320956E 01

STATION  FLOYD OBSERVES VEHICLE AT    0.55880000E 04   0.14166666E 00 DAYS
RELATIVE POSITION =   0.70892849E 07   0.10048137E 06   0.88483130E 07
RELATIVE VELOCITY =  -0.19305532E 05  -0.11656978E 05  -0.66669804E 04
R, RDOT, AZ, ELEV =   0.34559629E 04  -0.52964240E 01   0.17431796E 01   0.45496320E 01

TIME (SEC) =     0.12480000E 05
R (FEET) =    -0.12506162E 08   -0.38691732E 07    0.20892369E 08
R (KM  ) =    -0.38118782E 04   -0.11793240E 04    0.63679941E 04
V (KPS)  =    -0.51471968E 01   -0.37283147E 01   -0.35615086E 01

STATION  FLOYD OBSERVES VEHICLE AT    0.55880000E 04   0.14444444E 00 DAYS
RELATIVE POSITION =   0.27175024E 07  -0.26458066E 07   0.66346425E 07
RELATIVE VELOCITY =  -0.16976338E 05  -0.11121877E 05  -0.11684740E 05
R, RDOT, AZ, ELEV =   0.23293499E 04  -0.37582777E 01   0.23568691E 02   0.20884031E 02

TIME (SEC) =     0.12720000E 05
R (FEET) =    -0.16188274E 08   -0.66748812E 07    0.17554200E 08
R (KM  ) =    -0.49341860E 04   -0.20345038E 04    0.53505201E 04
V (KPS)  =    -0.41682590E 01   -0.33687433E 01   -0.48770738E 01

STATION  FLOYD OBSERVES VEHICLE AT    0.55880000E 04   0.14722221E 00 DAYS
RELATIVE POSITION =  -0.98835050E 06  -0.51852826E 07   0.32964732E 07
RELATIVE VELOCITY =  -0.13784014E 05  -0.99439115E 04  -0.16000898E 05
R, RDOT, AZ, ELEV =   0.18968928E 04   0.60921264E 00   0.74734591E 02   0.32489439E 02

TIME (SEC) =     0.12960000E 05
R (FEET) =    -0.19015495E 08   -0.91283462E 07    0.13285419E 08
R (KM  ) =    -0.57959228E 04   -0.27823199E 04    0.40493958E 04
V (KPS)  =    -0.29853239E 01   -0.28378210E 01   -0.59163659E 01

STATION  FLOYD OBSERVES VEHICLE AT    0.55880000E 04   0.14999999E 00 DAYS
RELATIVE POSITION =  -0.38439671E 07  -0.73729719E 07  -0.97230725E 06
RELATIVE VELOCITY =  -0.99223738E 04  -0.82041112E 04  -0.19410649E 05
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R, RDOT, AZ, ELEV =    0.25516362E 04   0.42781932E 01   0.11956373E 03   0.19062392E 02

TIME (SEC) =      0.13200000E 05
R (FEET) =    -0.20852869E 08  -0.11106847E 08   0.83222972E 07
R (KM  ) =    -0.63559545E 04  -0.33853670E 04   0.25366362E 04
V (KPS)  =    -0.16644604E 01  -0.21674909E 01  -0.66343052E 01

STATION  FLOYD OBSERVES VEHICLE AT     0.55880000E 04   0.15277777E 00 DAYS
RELATIVE POSITION =  -0.57143845E 07  -0.90862346E 07  -0.59354296E 07
RELATIVE VELOCITY =  -0.56081736E 04  -0.60072751E 04  -0.21766093E 05
R, RDOT, AZ, ELEV =   0.37385328E 04   0.53632025E 01   0.13757518E 03   0.43884459E 01

TIME (SEC) =      0.13440000E 05
R (FEET) =    -0.21618809E 08  -0.12514824E 08   0.29297298E 07
R (KM  ) =    -0.65894129E 04  -0.38145183E 04   0.89298165E 03
V (KPS)  =    -0.27490628E 00  -0.13947068E 01  -0.70035629E 01

TIME (SEC) =      0.13680000E 05
R (FEET) =    -0.21286370E 08  -0.13287066E 08  -0.26125972E 07
R (KM  ) =    -0.64880856E 04  -0.40498977E 04  -0.79631964E 03
V (KPS)  =     0.11142524E 01  -0.55934119E 00  -0.70140427E 01

TIME (SEC) =      0.13920000E 05
R (FEET) =    -0.19882106E 08  -0.13390327E 08  -0.80234124E 07
R (KM  ) =    -0.60600660E 04  -0.40813716E 04  -0.24455361E 04
V (KPS)  =     0.24367732E 01   0.29763971E 00  -0.66717128E 01

TIME (SEC) =      0.14160000E 05
R (FEET) =    -0.17482982E 08  -0.12823590E 08  -0.13032017E 08
R (KM  ) =    -0.53288129E 04  -0.39086302E 04  -0.39721588E 04
V (KPS)  =     0.36313298E 01   0.11356877E 01  -0.59971134E 01

TIME (SEC) =      0.14400000E 05
R (FEET) =    -0.14211813E 08  -0.11617223E 08  -0.17389190E 08
R (KM  ) =    -0.43317606E 04  -0.35409296E 04  -0.53002252E 04
V (KPS)  =     0.46430767E 01   0.19158847E 01  -0.50238059E 01
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SID 65-1203-3

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TIME (SEC) =     0.14640000E 05
R (FEET) =   -0.10231632E 08  -0.98312740E 07  -0.20876838E 08
R (KM  ) =   -0.31186016E 04  -0.29965723E 04  -0.63632601E 04
V (KPS)  =    0.54248813E 01   0.26019343E 01  -0.37969480E 01

TIME (SEC) =     0.14880000E 05
R (FEET) =   -0.57391600E 07  -0.75530285E 07  -0.23316585E 08
R (KM  ) =   -0.17492960E 04  -0.23021631E 04  -0.71068952E 04
V (KPS)  =    0.59384499E 01   0.31610605E 01  -0.23720379E 01

TIME (SEC) =     0.15120000E 05
R (FEET) =   -0.95741253E 06  -0.48939003E 07  -0.24577414E 08
R (KM  ) =   -0.29181934E 03  -0.14916608E 04  -0.74911958E 04
V (KPS)  =    0.61555310E 01   0.35649314E 01  -0.81376586E 00

TIME (SEC) =     0.15360000E 05
R (FEET) =    0.38727241E 07  -0.19855283E 07  -0.24582417E 08
R (KM  ) =    0.11804063E 04  -0.60518902E 03  -0.74927206E 04
V (KPS)  =    0.60593351E 01   0.37907340E 01   0.80523955E 00

TIME (SEC) =     0.15600000E 05
R (FEET) =    0.85021106E 07   0.10250267E 07  -0.23314470E 08
R (KM  ) =    0.25914433E 04   0.31242814E 03  -0.71062504E 04
V (KPS)  =    0.56461936E 01   0.38224556E 01   0.24060351E 01

TIME (SEC) =     0.15840000E 05
R (FEET) =    0.12684462E 08   0.39812406E 07  -0.20820381E 08
R (KM  ) =    0.38662241E 04   0.12134821E 04  -0.63460521E 04
V (KPS)  =    0.49273378E 01   0.36523703E 01   0.39057429E 01

TIME (SEC) =     0.16080000E 05
R (FEET) =    0.16188795E 08   0.67243114E 07  -0.17212709E 08
R (KM  ) =    0.49343447E 04   0.20495701E 04  -0.52464336E 04
V (KPS)  =    0.39305018E 01   0.32826004E 01   0.52209722E 01
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SID 65-1203-3

TIME (SEC) =	0.16320000E 05		
R (FEET) =	0.18812899E 08	0.91015175E 07	-0.12668339E 08
R (KM) =	0.57341716E 04	0.27741425E 04	-0.38613097E 04
V (KPS) =	0.27008806E 01	0.27265087E 01	0.62724894E 01
TIME (SEC) =	0.16560000E 05		
R (FEET) =	0.20397020E 08	0.10975427E 08	-0.74229208E 07
R (KM) =	0.62170117E 04	0.33453102E 04	-0.22625063E 04
V (KPS) =	0.13008514E 01	0.20095492E 01	0.69910647E 01
TIME (SEC) =	0.16800000E 05		
R (FEET) =	0.20836601E 08	0.12233389E 08	-0.17604576E 07
R (KM) =	0.63509961E 04	0.37287370E 04	-0.53658749E 03
V (KPS) =	-0.19217072E 00	0.11691210E 01	0.73240266E 01
TIME (SEC) =	0.17040000E 05		
R (FEET) =	0.20092514E 08	0.12796386E 08	0.40021355E 07
R (KM) =	0.61241982E 04	0.39003386E 04	0.12198509E 04
V (KPS) =	-0.16901255E 01	0.25302464E 00	0.72415684E 01
TIME (SEC) =	0.17280000E 05		
R (FEET) =	0.18197033E 08	0.12626118E 08	0.95349772E 07
R (KM) =	0.55464557E 04	0.38484407E 04	0.29062610E 04
V (KPS) =	-0.31008697E 01	-0.68365826E 00	0.67415059E 01
TIME (SEC) =	0.17520000E 05		
R (FEET) =	0.15254090E 08	0.11729103E 08	0.14517871E 08
R (KM) =	0.46494467E 04	0.35750307E 04	0.44250470E 04
V (KPS) =	-0.43361043E 01	-0.15830006E 01	0.58512022E 01
TIME (SEC) =	0.17760000E 05		
R (FEET) =	0.11433151E 08	0.10157009E 08	0.18663247E 08
R (KM) =	0.34848244E 04	0.30958564E 04	0.56885576E 04
V (KPS) =	-0.53193813E 01	-0.23893352E 01	0.46259245E 01

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TIME (SEC) =     0.18000000E 05
R (FEET) =     0.69571167E 07   0.80029212E 07   0.21736554E 08
R (KM  ) =     0.21205292E 04   0.24392904E 04   0.66253017E 04
V (KPS)  =    -0.59927244E 01  -0.30541303E 01   0.31437452E 01

TIME (SEC) =     0.18240000E 05
R (FEET) =     0.20858091E 07   0.53940797E 07   0.23571531E 08
R (KM  ) =     0.63575462E 03   0.16441155E 04   0.71846028E 04
V (KPS)  =    -0.63207557E 01  -0.35397798E 01   0.14980398E 01

TIME (SEC) =     0.18480000E 05
R (FEET) =    -0.29026961E 07   0.24821663E 07   0.24078941E 08
R (KM  ) =    -0.88474178E 03   0.75656429E 03   0.73392611E 04
V (KPS)  =    -0.62919702E 01  -0.38218380E 01  -0.21091365E 00

TIME (SEC) =     0.18720000E 05
R (FEET) =    -0.77305726E 07  -0.56746135E 06   0.23248649E 08
R (KM  ) =    -0.23562785E 04  -0.17296222E 03   0.70861881E 04
V (KPS)  =    -0.59175211E 01  -0.38896620E 01  -0.18838243E 01

STATION  FLOYD OBSERVES VEHICLE AT    0.55880000E 04   0.21666665E 00 DAYS
RELATIVE POSITION =   0.54064128E 07   0.72220319E 07   0.89909220E 07
RELATIVE VELOCITY =  -0.19982458E 05  -0.11803394E 05  -0.61805259E 04
R, RDOT, AZ, ELEV =   0.38821485E 04  -0.59551042E 01   0.34426167E 03   0.38074893E 00

TIME (SEC) =     0.18960000E 05
R (FEET) =    -0.12136934E 08  -0.35864460E 07   0.21146007E 08
R (KM  ) =    -0.36993374E 04  -0.10931487E 04   0.64453030E 04
V (KPS)  =    -0.52282730E 01  -0.37457783E 01  -0.34289141E 01

STATION  FLOYD OBSERVES VEHICLE AT    0.55880000E 04   0.21944443E 00 DAYS
RELATIVE POSITION =   0.86172112E 06   0.44317561E 07   0.68882807E 07
RELATIVE VELOCITY =  -0.17737823E 05  -0.11341422E 05  -0.11249718E 05
R, RDOT, AZ, ELEV =   0.25103280E 04  -0.52936226E 01   0.33498912E 03   0.17579834E 02

TIME (SEC) =     0.19200000E 05
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R (FEET) =    -0.15891706E 08  -0.64131680E 07   0.17903850E 08
R (KM  ) =    -0.48437920E 04  -0.19547336E 04   0.54570934E 04
V (KPS)  =    -0.42709973E 01  -0.34043745E 01  -0.47667484E 01

STATION  FLOYD OBSERVES VEHICLE AT    0.55880000E 04   0.22222221E 00 DAYS
RELATIVE POSITION =  -0.30353632E 07   0.18312870E 07   0.36461230E 07
RELATIVE VELOCITY =  -0.14613326E 05  -0.10231708E 05  -0.15638938E 05
R, RDOT, AZ, ELEV =   0.15500287E 04  -0.18821169E 01   0.29647845E 03   0.45683615E 02

TIME (SEC) =     0.19440000E 05
R (FEET) =    -0.18806276E 08  -0.89010794E 07   0.13711449E 08
R (KM  ) =    -0.57321528E 04  -0.27130490E 04   0.41792498E 04
V (KPS)  =    -0.31036147E 01  -0.28892936E 01  -0.58334138E 01

STATION  FLOYD OBSERVES VEHICLE AT    0.55880000E 04   0.22499999E 00 DAYS
RELATIVE POSITION =  -0.60961825E 07  -0.43289662E 06  -0.54627725E 06
RELATIVE VELOCITY =  -0.10799973E 05  -0.85524751E 04  -0.19138497E 05
R, RDOT, AZ, ELEV =   0.18702220E 04   0.39737843E 01   0.21679903E 03   0.34752239E 02

TIME (SEC) =     0.19680000E 05
R (FEET) =    -0.20740834E 08  -0.10925361E 08   0.88016855E 07
R (KM  ) =    -0.63218063E 04  -0.33300501E 04   0.26827537E 04
V (KPS)  =    -0.17920125E 01  -0.22318152E 01  -0.65822227E 01

STATION  FLOYD OBSERVES VEHICLE AT    0.55880000E 04   0.22777776E 00 DAYS
RELATIVE POSITION =  -0.81803839E 07  -0.22360444E 07  -0.54560412E 07
RELATIVE VELOCITY =  -0.65129410E 04  -0.64063423E 04  -0.21595219E 05
R, RDOT, AZ, ELEV =   0.30737253E 04   0.36046298E 01   0.19658375E 03   0.11978341E 02

TIME (SEC) =     0.19920000E 05
R (FEET) =    -0.21603693E 08  -0.12387911E 08   0.34373230E 07
R (KM  ) =    -0.65863298E 04  -0.37758352E 04   0.10476960E 04
V (KPS)  =    -0.40518202E 00  -0.14684221E 01  -0.69842241E 01

TIME (SEC) =     0.20160000E 05
R (FEET) =    -0.21377798E 08  -0.13220668E 08  -0.21028136E 07
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R (KM   ) =   -0.65159528E 04  -0.40296595E 04  -0.64093757E 03
V (KPS)   =    0.98764368E 00  -0.63870059E 00  -0.70277573E 01

TIME (SEC) =    0.20400000E 05
R (FEET) =    -0.20069799E 08  -0.13387372E 08  -0.75371117E 07
R (KM   ) =   -0.61172748E 04  -0.40804711E 04  -0.22973116E 04
V (KPS)   =    0.23198380E 01   0.21650551E 00  -0.67173377E 01

TIME (SEC) =    0.20640000E 05
R (FEET) =    -0.17757139E 08  -0.12883955E 08  -0.12593446E 08
R (KM   ) =   -0.54123759E 04  -0.39270295E 04  -0.38384825E 04
V (KPS)   =    0.35295111E 01   0.10566321E 01  -0.60721902E 01

TIME (SEC) =    0.20880000E 05
R (FEET) =    -0.14558615E 08  -0.11737796E 08  -0.17020180E 08
R (KM   ) =   -0.44374657E 04  -0.35776803E 04  -0.51877507E 04
V (KPS)   =    0.45611095E 01   0.18426258E 01  -0.51247009E 01

TIME (SEC) =    0.21120000E 05
R (FEET) =    -0.10633854E 08  -0.10006100E 08  -0.20595934E 08
R (KM   ) =   -0.32411986E 04  -0.30498592E 04  -0.62776407E 04
V (KPS)   =    0.53666759E 01   0.25379523E 01  -0.39189864E 01

TIME (SEC) =    0.21360000E 05
R (FEET) =    -0.61768613E 07  -0.77735452E 07  -0.23138284E 08
R (KM   ) =   -0.18827073E 04  -0.23693766E 04  -0.70525490E 04
V (KPS)   =    0.59069847E 01   0.31094977E 01  -0.25096307E 01

TIME (SEC) =    0.21600000E 05
R (FEET) =    -0.14087010E 07  -0.51492306E 07  -0.24511497E 08
R (KM   ) =   -0.42937207E 03  -0.15694855E 04  -0.74711044E 04
V (KPS)   =    0.61527382E 01   0.35284901E 01  -0.96052851E 00

TIME (SEC) =    0.21840000E 05
R (FEET) =     0.34308024E 07  -0.22628807E 07  -0.24633377E 08
R (KM   ) =    0.10457086E 04  -0.68972602E 03  -0.75082534E 04
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V (KPS)   =     0.60859676E 01    0.37715536E 01    0.65633512E 00

TIME (SEC) =     0.22080000E 05
R (FEET) =      0.80926073E 07    0.73986849E 06   -0.23481072E 08
R (KM   ) =     0.24666267E 04    0.22551192E 03   -0.71570309E 04
V (KPS)   =     0.57016855E 01    0.38219772E 01    0.22624734E 01

TIME (SEC) =     0.22320000E 05
R (FEET) =      0.12329417E 08    0.37033030E 07   -0.21095399E 08
R (KM   ) =     0.37580063E 04    0.11287667E 04   -0.64298775E 04
V (KPS)   =     0.50096681E 01    0.36711858E 01    0.37751926E 01

TIME (SEC) =     0.22560000E 05
R (FEET) =      0.15908037E 08    0.64686969E 07   -0.17582924E 08
R (KM   ) =     0.48487697E 04    0.19716588E 04   -0.53592753E 04
V (KPS)   =     0.40360991E 01    0.33203065E 01    0.51109161E 01

TIME (SEC) =     0.22800000E 05
R (FEET) =      0.18622822E 08    0.88825754E 07   -0.13114873E 08
R (KM   ) =     0.56762361E 04    0.27074090E 04   -0.39974132E 04
V (KPS)   =     0.28246101E 01    0.27815905E 01    0.61897556E 01

TIME (SEC) =     0.23040000E 05
R (FEET) =      0.20309395E 08    0.10805857E 08   -0.79219634E 07
R (KM   ) =     0.61903036E 04    0.32936253E 04   -0.24146144E 04
V (KPS)   =     0.14361378E 01    0.20793305E 01    0.69412692E 01

TIME (SEC) =     0.23280000E 05
R (FEET) =      0.20857557E 08    0.12123345E 08   -0.22844497E 07
R (KM   ) =     0.63573835E 04    0.36951955E 04   -0.69630025E 03
V (KPS)   =    -0.53035772E-01    0.12498234E 01    0.73109934E 01

TIME (SEC) =     0.23520000E 05
R (FEET) =      0.20221827E 08    0.12752676E 08    0.34828997E 07
R (KM   ) =     0.61636130E 04    0.38870158E 04    0.10615878E 04
V (KPS)   =    -0.15554807E 01    0.33996401E 00    0.72668271E 01
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TIME (SEC) =    0.23760000E 05
R (FEET) =    0.18427881E 08    0.12651614E 08    0.90504092E 07
R (KM  ) =    0.56168182E 04    0.38562120E 04    0.27585647E 04
V (KPS)  =   -0.29790202E 01   -0.59573795E 00    0.68039832E 01

TIME (SEC) =    0.24000000E 05
R (FEET) =    0.15573349E 08    0.11822452E 08    0.14096012E 08
R (KM  ) =    0.47467569E 04    0.36034834E 04    0.42964644E 04
V (KPS)  =   -0.42345966E 01   -0.14994911E 01    0.59472025E 01

TIME (SEC) =    0.24240000E 05
R (FEET) =    0.11822261E 08    0.10312700E 08    0.18328293E 08
R (KM  ) =    0.36034250E 04    0.31433109E 04    0.55864638E 04
V (KPS)  =   -0.52443380E 01   -0.23153002E 01    0.47494245E 01

TIME (SEC) =    0.24480000E 05
R (FEET) =    0.73934132E 07    0.82117181E 07    0.21507203E 08
R (KM  ) =    0.22535123E 04    0.25029317E 04    0.65553954E 04
V (KPS)  =   -0.59483581E 01   -0.29938878E 01    0.32869633E 01

TIME (SEC) =    0.24720000E 05
R (FEET) =    0.25441552E 07    0.56437401E 07    0.23459870E 08
R (KM  ) =    0.77545849E 03    0.17202120E 04    0.71505685E 04
V (KPS)  =   -0.63091298E 01   -0.34966043E 01    0.16521504E 01

TIME (SEC) =    0.24960000E 05
R (FEET) =   -0.24481798E 07    0.27583537E 07    0.24089922E 08
R (KM  ) =   -0.74620519E 03    0.84074519E 03    0.73426083E 04
V (KPS)  =   -0.63130025E 01   -0.37977973E 01   -0.55040904E-01

TIME (SEC) =    0.25200000E 05
R (FEET) =   -0.73048990E 07   -0.28021548E 06    0.23380136E 08
R (KM  ) =   -0.22265332E 04   -0.85409679E 02    0.71262654E 04
V (KPS)  =   -0.59691786E 01   -0.38855891E 01   -0.17349785E 01
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TIME (SEC) =      0.25440000E 05
R (FEET) =    -0.11762831E 08   -0.33037839E 07    0.21389269E 08
R (KM  ) =    -0.35853110E 04   -0.10069933E 04    0.65194493E 04
V (KPS)  =    -0.53068835E 01   -0.37613367E 01   -0.32950226E 01

STATION  FLOYD OBSERVES VEHICLE AT     0.55880000E 04   0.29444443E 00 DAYS
RELATIVE POSITION =  -0.38379686E 07   0.97519864E 07   0.71315427E 07
RELATIVE VELOCITY =  -0.18363077E 05  -0.11762454E 05  -0.10810442E 05
R, RDOT, AZ, ELEV =   0.38637550E 04  -0.29172418E 01   0.31884184E 03   0.11776330E 01

TIME (SEC) =      0.25680000E 05
R (FEET) =    -0.15588499E 08   -0.61500545E 07    0.18244390E 08
R (KM  ) =    -0.47513746E 04   -0.18745366E 04    0.55608900E 04
V (KPS)  =    -0.43715177E 01   -0.34381911E 01   -0.46545100E 01

STATION  FLOYD OBSERVES VEHICLE AT     0.55880000E 04   0.29722220E 00 DAYS
RELATIVE POSITION =  -0.78933306E 07   0.70424041E 07   0.39866632E 07
RELATIVE VELOCITY =  -0.15304259E 05  -0.10719014E 05  -0.15270702E 05
R, RDOT, AZ, ELEV =   0.34456370E 04  -0.41967691E 00   0.29275170E 03   0.60708103E 01

TIME (SEC) =      0.25920000E 05
R (FEET) =    -0.18589032E 08   -0.86710477E 07    0.14130080E 08
R (KM  ) =    -0.56659371E 04   -0.26429353E 04    0.43068483E 04
V (KPS)  =    -0.32204178E 01   -0.29391285E 01   -0.57480546E 01

STATION  FLOYD OBSERVES VEHICLE AT     0.55880000E 04   0.29999998E 00 DAYS
RELATIVE POSITION =  -0.11125915E 08   0.46540586E 07  -0.12764712E 06
RELATIVE VELOCITY =  -0.11537357E 05  -0.90985907E 04  -0.18858447E 05
R, RDOT, AZ, ELEV =   0.36761272E 04   0.22346882E 01   0.26506046E 03   0.43528510E 01

TIME (SEC) =      0.26160000E 05
R (FEET) =    -0.20619829E 08   -0.10739913E 08    0.92757185E 07
R (KM  ) =    -0.62849240E 04   -0.32735256E 04    0.28272390E 04
V (KPS)  =    -0.19186561E 01   -0.22947505E 01   -0.65273771E 01
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TIME (SEC) =     0.26400000E 05
R (FEET) =    -0.21589126E 08   -0.12256057E 08    0.39418338E 07
R (KM  ) =    -0.65803656E 04   -0.37356461E 04    0.12014709E 04
V (KPS)  =    -0.53514936E 00   -0.15410523E 01   -0.69619086E 01

TIME (SEC) =     0.26640000E 05
R (FEET) =    -0.21459764E 08   -0.13148606E 08   -0.15937285E 07
R (KM  ) =    -0.65409360E 04   -0.40076951E 04   -0.48576844E 03
V (KPS)  =     0.86075061E 00   -0.71731815E 00   -0.70384223E 01

TIME (SEC) =     0.26880000E 05
R (FEET) =    -0.20248476E 08   -0.13378314E 08   -0.70491323E 07
R (KM  ) =    -0.61717355E 04   -0.40777101E 04   -0.21485755E 04
V (KPS)  =     0.22020569E 01    0.13574688E 00   -0.67599743E 01

TIME (SEC) =     0.27120000E 05
R (FEET) =    -0.18023153E 08   -0.12938071E 08   -0.12150908E 08
R (KM  ) =    -0.54934572E 04   -0.39435240E 04   -0.37035967E 04
V (KPS)  =     0.34263282E 01    0.97757280E 00   -0.61444656E 01

TIME (SEC) =     0.27360000E 05
R (FEET) =    -0.14898535E 08   -0.11852271E 08   -0.16645107E 08
R (KM  ) =    -0.45410734E 04   -0.36125722E 04   -0.50734285E 04
V (KPS)  =     0.44773204E 01    0.17689854E 01   -0.52230975E 01

TIME (SEC) =     0.27600000E 05
R (FEET) =    -0.11030786E 08   -0.10175275E 08   -0.20307154E 08
R (KM  ) =    -0.33621834E 04   -0.31014238E 04   -0.61896204E 04
V (KPS)  =     0.53062660E 01    0.24732238E 01   -0.403893 0E 01

TIME (SEC) =     0.27840000E 05
R (FEET) =    -0.66111306E 07   -0.79891330E 07   -0.22950655E 08
R (KM  ) =    -0.20150726E 04   -0.24350877E 04   -0.69953597E 04
V (KPS)  =     0.58730196E 01    0.30568490E 01   -0.26456407E 01

TIME (SEC) =     0.28080000E 05
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R (FEET) =   -0.18586121E 07  -0.54006081E 07  -0.24435235E 08
R (KM  ) =   -0.56650495E 03  -0.16461053E 04  -0.74478597E 04
V (KPS)  =    0.61472495E 01   0.34906604E 01  -0.11062994E 01

TIME (SEC) =    0.28320000E 05
R (FEET) =    0.29880998E 07  -0.25374747E 07  -0.24673468E 08
R (KM  ) =    0.91077281E 03  -0.77342227E 03  -0.75204730E 04
V (KPS)  =    0.61098243E 01   0.37507350E 01   0.50776216E 00

TIME (SEC) =    0.28560000E 05
R (FEET) =    0.76801453E 07   0.45609812E 06  -0.23636822E 08
R (KM  ) =    0.23409083E 04   0.13901871E 03  -0.72045034E 04
V (KPS)  =    0.57544516E 01   0.38196788E 01   0.21185299E 01

TIME (SEC) =    0.28800000E 05
R (FEET) =    0.11969329E 08   0.34252736E 07  -0.21360155E 08
R (KM  ) =    0.36482515E 04   0.10440234E 04  -0.65105753E 04
V (KPS)  =    0.50894663E 01   0.36880852E 01   0.36435245E 01

TIME (SEC) =    0.29040000E 05
R (FEET) =    0.15620369E 08   0.62114784E 07  -0.17944042E 08
R (KM  ) =    0.47610884E 04   0.18932586E 04  -0.54693441E 04
V (KPS)  =    0.41395087E 01   0.33561024E 01   0.49990244E 01

TIME (SEC) =    0.29280000E 05
R (FEET) =    0.18424299E 08   0.86605666E 07  -0.13554015E 08
R (KM  ) =    0.56157263E 04   0.26397407E 04  -0.41312636E 04
V (KPS)  =    0.29465458E 01   0.28348815E 01   0.61045320E 01

TIME (SEC) =    0.29520000E 05
R (FEET) =    0.20212231E 08   0.10631897E 08  -0.84157952E 07
R (KM  ) =    0.61606879E 04   0.32406022E 04  -0.25651344E 04
V (KPS)  =    0.15703587E 01   0.21475594E 01   0.68884473E 01

TIME (SEC) =    0.29760000E 05
R (FEET) =    0.20868415E 08   0.12007817E 08  -0.28057717E 07
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R (KM) =	0.63606929E 04	0.36599828E 04	-0.85519923E 03
V (KPS) =	0.85762863E-01	0.13293242E 01	0.72945701E 01
TIME (SEC) =	0.30000000E 05		
R (FEET) =	0.20341082E 08	0.12702705E 08	0.29635913E 07
R (KM) =	0.61999619E 04	0.38717846E 04	0.90330264E 03
V (KPS) =	-0.14203945E 01	0.42614292E 00	0.72885491E 01
TIME (SEC) =	0.30240000E 05		
R (FEET) =	0.18649322E 08	0.12670445E 08	0.85630000E 07
R (KM) =	0.56843133E 04	0.38619517E 04	0.26100024E 04
V (S) =	-0.28559656E 01	-0.50807703E 00	0.68630181E 01
TIME (SEC) =	0.30480000E 05		
R (FEET) =	0.15884431E 08	0.11909135E 08	0.13668713E 08
R (KM) =	0.48415744E 04	0.36299044E 04	0.41662237E 04
V (KPS) =	-0.41311989E 01	-0.14157239E 01	0.60400913E 01
TIME (SEC) =	0.30720000E 05		
R (FEET) =	0.12204904E 08	0.10462125E 08	0.17985649E 08
R (KM) =	0.37200547E 04	0.31888557E 04	0.54820257E 04
V (KPS) =	-0.51668582E 01	-0.22405159E 01	0.48703491E 01
TIME (SEC) =	0.30960000E 05		
R (FEET) =	0.78253226E 07	0.84150135E 07	0.21268397E 08
R (KM) =	0.23851583E 04	0.25648961E 04	0.64826075E 04
V (KPS) =	-0.59011816E 01	-0.29324676E 01	0.34282963E 01
TIME (SEC) =	0.31200000E 05		
R (FEET) =	0.30004174E 07	0.58889704E 07	0.23337576E 08
R (KM) =	0.91452723E 03	0.17949582E 04	0.71132930E 04
V (KPS) =	-0.62945108E 01	-0.34519110E 01	0.18051600E 01
TIME (SEC) =	0.31440000E 05		
R (FEET) =	-0.19933834E 07	0.30314032E 07	0.24089726E 08
R (KM) =	-0.60758326E 03	0.92397170E 03	0.73425485E 04

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V (KPS)   =   -0.63310476E 01  -0.37720048E 01   0.10054340E 00

TIME (SEC) =    0.31680000E 05
R (FEET) =    -0.68766511E 07   0.53302892E 04   0.23500535E 08
R (KM   ) =   -0.20960032E 04   0.16246721E 01   0.71629631E 04
V (KPS)   =   -0.60180256E 01  -0.38796393E 01  -0.15856297E 01

TIME (SEC) =    0.31920000E 05
R (FEET) =    -0.11384066E 08  -0.30213339E 07   0.21622128E 08
R (KM   ) =   -0.34698634E 04  -0.92090256E 03   0.65904245E 04
V (KPS)   =   -0.53830054E 01  -0.37750006E 01  -0.31599058E 01

TIME (SEC) =    0.32160000E 05
R (FEET) =    -0.15278834E 08  -0.58856856E 07   0.18575747E 08
R (KM   ) =   -0.46569986E 04  -0.17939570E 04   0.56618876E 04
V (KPS)   =   -0.44700878E 01  -0.34701945E 01  -0.45404207E 01

TIME (SEC) =    0.32400000E 05
R (FEET) =    -0.18363921E 08  -0.84383960E 07   0.14541184E 08
R (KM   ) =   -0.55973232E 04  -0.25720231E 04   0.44321530E 04
V (KPS)   =   -0.33356900E 01  -0.29873178E 01  -0.56603431E 01

TIME (SEC) =    0.32640000E 05
R (FEET) =    -0.20489972E 08  -0.10550640E 08   0.97442305E 07
R (KM   ) =   -0.62453434E 04  -0.32158352E 04   0.29700414E 04
V (KPS)   =   -0.20443414E 01  -0.23562797E 01  -0.64698124E 01

TIME (SEC) =    0.32880000E 05
R (FEET) =    -0.21560185E 08  -0.12119385E 08   0.44430558E 07
R (KM   ) =   -0.65715444E 04  -0.36939886E 04   0.13542434E 04
V (KPS)   =   -0.66475108E 00  -0.16125724E 01  -0.69366487E 01

TIME (SEC) =    0.33120000E 05
R (FEET) =    -0.21532301E 08  -0.13070982E 08  -0.10855668E 07
R (KM   ) =   -0.65630453E 04  -0.39840353E 04  -0.33088075E 03
V (KPS)   =    0.73363142E 00  -0.79516312E 00  -0.70460575E 01
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TIME (SEC) =     0.33360000E 05
R (FEET) =    -0.20418129E 08   -0.13363226E 08   -0.65596929E 07
R (KM   ) =   -0.62234456E 04   -0.40731114E 04   -0.19993944E 04
V (KPS)  =     0.20834835E 01    0.55396150E-01   -0.67996305E 01

TIME (SEC) =     0.33600000E 05
R (FEET) =    -0.18280977E 08   -0.12985983E 08   -0.11704619E 08
R (KM   ) =   -0.55720419E 04   -0.39581277E 04   -0.35675677E 04
V (KPS)  =     0.33218317E 01    0.89854551E 00   -0.62139358E 01

TIME (SEC) =     0.33840000E 05
R (FEET) =    -0.15231482E 08   -0.11960665E 08   -0.16264186E 08
R (KM   ) =   -0.46425558E 04   -0.36456107E 04   -0.49573239E 04
V (KPS)  =     0.43917584E 01    0.16950024E 01   -0.53189796E 01

TIME (SEC) =     0.34080000E 05
R (FEET) =    -0.11422299E 08   -0.10338784E 08   -0.20010695E 08
R (KM   ) =   -0.34815168E 04   -0.31512615E 04   -0.60992598E 04
V (KPS)  =     0.52436947E 01    0.24077883E 01   -0.41567705E 01

TIME (SEC) =     0.34320000E 05
R (FEET) =    -0.70417986E 07   -0.81997416E 07   -0.22753875E 08
R (KM   ) =   -0.21463402E 04   -0.24992812E 04   -0.69353810E 04
V (KPS)  =     0.58365911E 01    0.30031540E 01   -0.27800250E 01

TIME (SEC) =     0.34560000E 05
R (FEET) =    -0.23069505E 07   -0.56479551E 07   -0.24348763E 08
R (KM   ) =   -0.70315850E 03   -0.17214967E 04   -0.74215030E 04
V (KPS)  =     0.61390932E 01    0.34514796E 01   -0.12510252E 01

TIME (SEC) =     0.34800000E 05
R (FEET) =     0.25448206E 07   -0.28092097E 07   -0.24702778E 08
R (KM   ) =    0.77566130E 03   -0.85624711E 03   -0.75294066E 04
V (KPS)  =     0.61309217E 01    0.37283106E 01    0.35958084E 00
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TIME (SEC) =	0.35040000E 05		
R (FEET) =	0.72649376E 07	0.17384398E 06	-0.23781758E 08
R (KM) =	0.22143530E 04	0.52987644E 02	-0.72486799E 04
V (KPS) =	0.58044958E 01	0.38155869E 01	0.19742731E 01
TIME (SEC) =	0.35280000E 05		
R (FEET) =	0.11604413E 08	0.31473015E 07	-0.21614630E 08
R (KM) =	0.35370250E 04	0.95929749E 03	-0.65881393E 04
V (KPS) =	0.51667210E 01	0.37030871E 01	0.35108139E 01
TIME (SEC) =	0.35520000E 05		
R (FEET) =	0.15325990E 08	0.59528149E 07	-0.18295985E 08
R (KM) =	0.46713618E 04	0.18144180E 04	-0.55766162E 04
V (KPS) =	0.42407037E 01	0.33899955E 01	0.48853725E 01
TIME (SEC) =	0.35760000E 05		
R (FEET) =	0.18217501E 08	0.84356504E 07	-0.13985630E 08
R (KM) =	0.55526943E 04	0.25711862E 04	-0.42628199E 04
V (KPS) =	0.30669447E 01	0.28863772E 01	0.60168896E 01
TIME (SEC) =	0.36000000E 05		
R (FEET) =	0.20105657E 08	0.10453697E 08	-0.89042277E 07
R (KM) =	0.61282043E 04	0.31862867E 04	-0.27140086E 04
V (KPS) =	0.17034566E 01	0.22142185E 01	0.68326601E 01
TIME (SEC) =	0.36240000E 05		
R (FEET) =	0.20869256E 08	0.11886939E 08	-0.33241944E 07
R (KM) =	0.63609493E 04	0.36231391E 04	-0.10132144E 04
V (KPS) =	0.22415662E 00	0.14075937E 01	0.72748013E 01
TIME (SEC) =	0.36480000E 05		
R (FEET) =	0.20450304E 08	0.12646578E 06	0.24444639E 07
R (KM) =	0.62332326E 04	0.38546770E 04	0.74507259E 03
V (KPS) =	-0.12849408E 01	0.51152258E 00	0.73067589E 01

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TIME (SEC) =      0.36720000E 05
R (FEET) =      0.18861319E 08    0.12682679E 08    0.80730226E 07
R (KM   ) =     0.57489302E 04    0.38656807E 04    0.24606573E 04
V (KPS)   =    -0.27317808E 01   -0.42072447E 00    0.69186119E 01

TIME (SEC) =      0.36960000E 05
R (FEET) =      0.16187233E 08    0.11989181E 08    0.13236245E 08
R (KM   ) =     0.49338686E 04    0.36543024E 04    0.40344075E 04
V (KPS)   =    -0.40259833E 01   -0.13317516E 01    0.61298462E 01

TIME (SEC) =      0.37200000E 05
R (FEET) =      0.12580935E 08    0.10605272E 08    0.17635555E 08
R (KM   ) =     0.38346690E 04    0.32324868E 04    0.53753171E 04
V (KPS)   =    -0.50870002E 01   -0.21650343E 01    0.49886567E 01

TIME (SEC) =      0.37440000E 05
R (FEET) =      0.82526665E 07    0.86127606E 07    0.21020335E 08
R (KM   ) =     0.25154127E 04    0.26251694E 04    0.64069980E 04
V (KPS)   =    -0.53512375E 01   -0.28699160E 01    0.35676887E 01

TIME (SEC) =      0.37680000E 05
R (FEET) -      0.34543811E 07    0.61296847E 07    0.23204797E 08
R (KM   ) =     0.10528954E 04    0.18683279E 04    0.70728221E 04
V (KPS)   =    -0.62769251E 01   -0.34057406E 01    0.19569993E 01

TIME (SEC) =      0.37920000E 05
R (FEET) =     -0.15385298E 07    0.33012047E 07    0.24078445E 08
R (KM   ) =    -0.46894387E 03    0.10062072E 04    0.73391100E 04
V (KPS)   =    -0.63461143E 01   -0.37444914E 01    0.25576593E 00

TIME (SEC) =      0.38160000E 05
R (FEET) =     -0.64460577E 07    0.28904150E 06    0.23609879E 08
R (KM   ) =    -0.19647584E 04    0.88099850E 02    0.71962913E 04
V (KPS)   =    -0.60640549E 01   -0.38718345E 01   -0.14358544E 01

TIME (SEC) =      0.38400000E 05
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R (FEET) =   -0.11000854E 08  -0.27392431E 07   0.21844557E 08
R (KM  ) =   -0.33530604E 04  -0.83492130E 03   0.66582211E 04
V (KPS)  =   -0.54566165E 01  -0.37867815E 01  -0.30236367E 01

TIME (SEC) =    0.38640000E 05
R (FEET) =   -0.14962913E 08  -0.56202215E 07   0.18897831E 08
R (KM  ) =   -0.45606959E 04  -0.17130435E 04   0.57600590E 04
V (KPS)  =   -0.45665706E 01  -0.35003850E 01  -0.44245504E 01

TIME (SEC) =    0.38880000E 05
R (FEET) =   -0.18131098E 08  -0.82032717E 07   0.14944642E 08
R (KM  ) =   -0.55263586E 04  -0.25003572E 04   0.45551268E 04
V (KPS)  =   -0.34493894E 01  -0.30338538E 01  -0.55703356E 01

TIME (SEC) =    0.39120000E 05
R (FEET) =   -0.20351387E 08  -0.10357684E 08   0.10207047E 08
R (KM  ) =   -0.62031029E 04  -0.31570222E 04   0.31111081E 04
V (KPS)  =   -0.21690161E 01  -0.24163855E 01  -0.64095758E 01

TIME (SEC) =    0.39360000E 05
R (FEET) =   -0.21521950E 08  -0.11978017E 08   0.49407984E 07
R (KM  ) =   -0.65598903E 04  -0.36508996E 04   0.15059554E 04
V (KPS)  =   -0.79393447E 00  -0.16829593E 01  -0.69084786E 01

TIME (SEC) =    0.39600000E 05
R (FEET) =   -0.21595447E 08  -0.12987897E 08  -0.57854236E 06
R (KM  ) =   -0.65822922E 04  -0.39587110E 04  -0.17633971E 03
V (KPS)  =    0.60634186E 00  -0.87220685E 00  -0.70506840E 01

TIME (SEC) =    0.39840000E 05
R (FEET) =   -0.20578749E 08  -0.13342185E 08  -0 60690248E 07
R (KM  ) =   -0.62724026E 04  -0.40666981E 04  -0.18498388E 04
V (KPS)  =    0.19641745E 01  -0.24511640E-01  -0.68363140E 01

TIME (SEC) =    0.40080000E 05
R (FEET) =   -0.18530549E 08  -0.13027739E 08  -0.11254833E 08
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R (KM  ) =    -0.56481114E 04   -0.39708548E 04   -0.34304730E 04
V (KPS)  =     0.32160817E 01    0.81959134E 00   -0.62805929E 01

TIME (SEC) =    0.40320000E 05
R (FEET) =    -0.15557358E 08   -0.12062994E 08   -0.15877646E 08
R (KM  ) =    -0.47418826E 04   -0.36768006E 04   -0.48395065E 04
V (KPS)  =     0.43044752E 01    0.16207171E 01   -0.54123282E 01

TIME (SEC) =    0.40560000E 05
R (FEET) =    -0.11808253E 08   -0.10496607E 08   -0.19706771E 08
R (KM  ) =    -0.35991555E 04   -0.31993658E 04   -0.60066239E 04
V (KPS)  =     0.51790087E 01    0.23416884E 01   -0.42724543E 01

TIME (SEC) =    0.40800000E 05
R (FEET) =    -0.74687076E 07   -0.84053301E 07   -0.22548117E 08
R (KM  ) =    -0.22764621E 04   -0.25619446E 04   -0.68726661E 04
V (KPS)  =     0.57977366E 01    0.29484518E 01   -0.29127444E 01

TIME (SEC) =    0.41040000E 05
R (FEET) =    -0.27535301E 07   -0.58911969E 07   -0.24252222E 08
R (KM  ) =    -0.83927596E 03   -0.17956368E 04   -0.73920772E 04
V (KPS)  =     0.61282973E 01    0.34109847E 01   -0.13946550E 01

TIME (SEC) =    0.41280000E 05
R (FEET) =     0.21011755E 07   -0.30779784E 07   -0.24721403E 08
R (KM  ) =     0.64043829E 03   -0.93816780E 03   -0.75350837E 04
V (KPS)  =     0.61492775E 01    0.37043141E 01    0.21185387E 00

TIME (SEC) =    0.41520000E 05
R (FEET) =     0.68472047E 07   -0.10676363E 06   -0.23915923E 08
R (KM  ) =     0.20870280E 04   -0.32541554E 02   -0.72895734E 04
V (KPS)  =     0.58518218E 01    0.38097286E 01    0.18297737E 01

TIME (SEC) =    0.41760000E 05
R (FEET) =     0.11234887E 08    0.28695359E 07   -0.21858810E 08
R (KM  ) =     0.34243937E 04    0.87463455E 03   -0.66625653E 04
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V (KPS)   =    0.52414213E 01   0.37162095E 01   0.33771362E 01

TIME (SEC) =    0.42000000E 05
R (FEET) =     0.15025107E 08   0.56928662E 07  -0.18638674E 08
R (KM   ) =    0.45796525E 04   0.17351856E 04  -0.56810678E 04
V (KPS)   =    0.43396561E 01   0.34219941E 01   0.47700374E 01

TIME (SEC) =    0.42240000E 05
R (FEET) =     0.18002599E 08   0.82079816E 07  -0.14409595E 08
R (KM   ) =    0.54871921E 04   0.25017928E 04  -0.43920446E 04
V (KPS)   =    0.31854667E 01   0.29360754E 01   0.59268974E 01

TIME (SEC) =    0.42480000E 05
R (FEET) =     0.19989811E 08   0.10271407E 08  -0.93870794E 07
R (KM   ) =    0.60928943E 04   0.31307249E 04  -0.28611818E 04
V (KPS)   =    0.18353752E 01   0.22792921E 01   0.67739687E 01

TIME (SEC) =    0.42720000E 05
R (FEET) =     0.20860168E 08   0.11760848E 08  -0.38394698E 07
R (KM   ) =    0.63581791E 04   0.35847066E 04  -0.11702704E 04
V (KPS)   =    0.36207226E 00   0.14846000E 01   0.72517353E 01

TIME (SEC) =    0.42960000E 05
R (FEET) =     0.20549517E 08   0.12584403E 08   0.19258027E 07
R (KM   ) =    0.62634927E 04   0.38357260E 04   0.58698466E 03
V (KPS)   =   -0.11492013E 01   0.59605817E 00   0.73214827E 01

TIME (SEC) =    0.43200000E 05
R (FEET) =     0.19063838E 08   0.12688391E 08   0.75807619E 07
R (KM   ) =    0.58106580E 04   0.38674215E 04   0.23106162E 04
V (KPS)   =   -0.26065460E 01  -0.33372920E 00   0.69707672E 01

TIME (SEC) =    0.43440000E 05
R (FEET) =     0.16481666E 08   0.12062623E 08   0.12798878E 08
R (KM   ) =    0.50236118E 04   0.36766874E 04   0.39010981E 04
V (KPS)   =   -0.39190207E 01  -0.12476264E 01   0.62164471E 01
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TIME (SEC) =	0.43680000E 05		
R (FEET) =	0.12950216E 08	0.10742134E 08	0.17278253E 08
R (KM) =	0.39472257E 04	0.32742024E 04	0.52664116E 04
V (KPS) =	-0.50048230E 01	-0.20889063E 01	0.51043077E 01
TIME (SEC) =	0.43920000E 05		
R (FEET) =	0.86752440E 07	0.88049027E 07	0.20763230E 08
R (KM) =	0.26442144E 04	0.26837343E 04	0.63286326E 04
V (KPS) =	-0.57985725E 01	-0.28062829E 01	0.37050778E 01
TIME (SEC) =	0.44160000E 05		
R (FEET) =	0.39058302E 07	0.63657975E 07	0.23061693E 08
R (KM) =	0.11904970E 04	0.19402951E 04	0.70292040E 04
V (KPS) =	-0.62564008E 01	-0.33581344E 01	0.21075982E 01
TIME (SEC) =	0.44400000E 05		
R (FEET) =	-0.10838565E 07	0.35676412E 07	0.24056178E 08
R (KM) =	-0.33035947E 03	0.10874170E 04	0.73323229E 04
V (KPS) =	-0.63582129E 01	-0.37152903E 01	0.41054828E 00
TIME (SEC) =	0.44640000E 05		
R (FEET) =	-0.60133585E 07	0.57077755E 06	0.23708205E 08
R (KM) =	-0.18328717E 04	0.17397300E 03	0.72262610E 04
V (KPS) =	-0.61072593E 01	-0.38621969E 01	-0.12857327E 01
TIME (SEC) =	0.44880000E 05		
R (FEET) =	-0.10613415E 08	-0.24576605E 07	0.22056537E 08
R (KM) =	-0.32349690E 04	-0.74909492E 03	0.67228325E 04
V (KPS) =	-0.55276959E 01	-0.37966912E 01	-0.28862901E 01
TIME (SEC) =	0.45120000E 05		
R (FEET) =	-0.14640923E 08	-0.53538052E 07	0.19210578E 08
R (KM) =	-0.44625532E 04	-0.16318398E 04	0.58553843E 04
V (KPS) =	-0.46609352E 01	-0.35287661E 01	-0.43069627E 01

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TIME (SEC) =    0.45360000E 05
R (FEET) =   -0.17890740E 08  -0.79658344E 07   0.15340308E 08
R (KM  ) =   -0.54530975E 04  -0.24279863E 04   0.46757258E 04
V (KPS)  =   -0.35614670E 01  -0.30787269E 01  -0.54780946E 01

TIME (SEC) =    0.45600000E 05
R (FEET) =   -0.20204202E 08  -0.10161182E 08   0.10664009E 08
R (KM  ) =   -0.61582409E 04  -0.30971283E 04   0.32503901E 04
V (KPS)  =   -0.22926304E 01  -0.24750534E 01  -0.63467143E 01

TIME (SEC) =    0.45840000E 05
R (FEET) =   -0.21474508E 08  -0.11832080E 08   0.54348515E 07
R (KM  ) =   -0.65454302E 04  -0.36064179E 04   0.16565427E 04
V (KPS)  =   -0.92264035E 00  -0.17521888E 01  -0.68774334E 01

TIME (SEC) =    0.46080000E 05
R (FEET) =   -0.21649241E 08  -0.12899457E 08  -0.72896501E 05
R (KM  ) =   -0.65986886E 04  -0.39317544E 04  -0.22218853E 02
V (KPS)  =    0.47894488E 00  -0.94841711E 00  -0.70523239E 01

TIME (SEC) =    0.46320000E 05
R (FEET) =   -0.20730325E 08  -0.13315271E 08  -0.55773857E 07
R (KM  ) =   -0.63186030E 04  -0.40584945E 04  -0.16999872E 04
V (KPS)  =    0.18441938E 01  -0.10393898E 00  -0.68700324E 01

TIME (SEC) =    0.46560000E 05
R (FEET) =   -0.18771822E 08  -0.13063387E 08  -0.10801777E 08
R (KM  ) =   -0.57216515E 04  -0.39817203E 04  -0.32923817E 04
V (KPS)  =    0.31091318E 01   0.74074735E 00  -0.63444342E 01

TIME (SEC) =    0.46800000E 05
R (FEET) =   -0.15876064E 08  -0.12159275E 08  -0.15485722E 08
R (KM  ) =   -0.48390243E 04  -0.37061471E 04  -0.47200480E 04
V (KPS)  =    0.42155247E 01   0.15461712E 01  -0.55031246E 01
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TIME (SEC) =    0.47040000E 05
R (FEET) =   -0.12188514E 08  -0.10648734E 08  -0.19395593E 08
R (KM  ) =   -0.37150591E 04  -0.32457341E 04  -0.59117767E 04
V (KPS)  =    0.51122552E 01   0.22749645E 01  -0.43859586E 01

TIME (SEC) =    0.47280000E 05
R (FEET) =   -0.78916781E 07  -0.86058445E 07  -0.22333570E 08
R (KM  ) =   -0.24053835E 04  -0.26230614E 04  -0.68072722E 04
V (KPS)  =    0.57564967E 01   0.28927843E 01  -0.30437528E 01

TIME (SEC) =    0.47520000E 05
R (FEET) =   -0.31981497E 07  -0.61302546E 07  -0.24145758E 08
R (KM  ) =   -0.97479603E 03  -0.18685016E 04  -0.73596270E 04
V (KPS)  =    0.61148918E 01   0.33692142E 01  -0.15371335E 01

TIME (SEC) =    0.47760000E 05
R (FEET) =    0.16573854E 07  -0.33436707E 07  -0.24729444E 08
R (KM  ) =    0.50517108E 03  -0.10191508E 04  -0.75375344E 04
V (KPS)  =    0.61649096E 01   0.36787791E 01   0.64646701E-01

TIME (SEC) =    0.48000000E 05
R (FEET) =    0.64271836E 07  -0.38558659E 06  -0.24039360E 08
R (KM  ) =    0.19590056E 04  -0.11752679E 03  -0.73271969E 04
V (KPS)  =    0.58964337E 01   0.38021315E 01   0.16851071E 01

TIME (SEC) =    0.48240000E 05
R (FEET) =    0.10860982E 08   0.25921297E 07  -0.22092677E 08
R (KM  ) =    0.33104274E 04   0.79008112E 03  -0.67338479E 04
V (KPS)  =    0.53135559E 01   0.37274717E 01   0.32425700E 01

TIME (SEC) =    0.48480000E 05
R (FEET) =    0.14717921E 08   0.54317898E 07  -0.18972042E 08
R (KM  ) =    0.44860224E 04   0.16556095E 04  -0.57826785E 04
V (KPS)  =    0.44363413E 01   0.34521073E 01   0.46530942E 01

TIME (SEC) =    0.48720000E 05
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R (FEET) =    0.17779784E 08   0.79777317E 07  -0.14825761E 08
R (KM  ) =    0.54192781E 04   0.24316126E 04  -0.45188919E 04
V (KPS)  =    0.33021645E 01   0.29839704E 01   0.58346332E 01

TIME (SEC) =    0.48960000E 05
R (FEET) =    0.19864835E 08   0.10085188E 08  -0.98641506E 07
R (KM  ) =    0.60548017E 04   0.30739652E 04  -0.30065931E 04
V (KPS)  =    0.19660539E 01   0.23427622E 01   0.67124385E 01

TIME (SEC) =    0.49200000E 05
R (FEET) =    0.20841240E 08   0.11629676E 08  -0.43513982E 07
R (KM  ) =    0.63524101E 04   0.35447252E 04  -0.13263062E 04
V (KPS)  =    0.49944887E 00   0.15603189E 01   0.72254182E 01

TIME (SEC) =    0.49440000E 05
R (FEET) =    0.20638761E 08   0.12516288E 08   0.14078326E 07
R (KM  ) =    0.62906945E 04   0.38149645E 04   0.42910738E 03
V (KPS)  =   -0.10132428E 01   0.67971666E 00   0.73327500E 01

TIME (SEC) =    0.49680000E 05
R (FEET) =    0.19256860E 08   0.12687654E 08   0.70864702E 07
R (KM  ) =    0.58694908E 04   0.38671970E 04   0.21599561E 04
V (KPS)  =   -0.24803321E 01  -0.24713536E 00   0.70194918E 01

TIME (SEC) =    0.49920000E 05
R (FEET) =    0.16767661E 08   0.12129501E 08   0.12356856E 08
R (KM  ) =    0.51107831E 04   0.36970719E 04   0.37663698E 04
V (KPS)  =   -0.38103758E 01  -0.11633956E 01   0.62998818E 01

TIME (SEC) =    0.50160000E 05
R (FEET) =    0.13312613E 08   0.10872709E 08   0.16913985E 08
R (KM  ) =    0.40576844E 04   0.33140018E 04   0.51553825E 04
V (KPS)  =   -0.49203858E 01  -0.20121821E 01   0.52172654E 01

TIME (SEC) =    0.50400000E 05
R (FEET) =    0.90929142E 07   0.89914157E 07   0.20497270E 08
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R (KM  ) =      0.27715202E 04   0.27405835E 04   0.62475679E 04
V (KPS)  =     -0.57432278E 01  -0.27416111E 01   0.38404209E 01

TIME (SEC) =      0.50640000E 05
R (FEET) =      0.43545792E 07   0.65972420E 07   0.22908416E 08
R (KM  ) =      0.13272757E 04   0.20108394E 04   0.69824851E 04
V (KPS)  =     -0.62329656E 01  -0.33091319E 01   0.22568972E 01

TIME (SEC) =      0.50880000E 05
R (FEET) =     -0.62955997E 06   0.38306202E 07   0.24023028E 08
R (KM  ) =     -0.19188988E 03   0.11675730E 04   0.73222191E 04
V (KPS)  =     -0.63673563E 01  -0.36844327E 01   0.56482632E 00

TIME (SEC) =      0.51120000E 05
R (FEET) =     -0.55787582E 07   0.85042227E 06   0.23795563E 08
R (KM  ) =     -0.17004055E 04   0.25920871E 03   0.72528875E 04
V (KPS)  =     -0.61476368E 01  -0.38507501E 01  -0.11353329E 01

TIME (SEC) =      0.51360000E 05
R (FEET) =     -0.10221955E 08  -0.21767225E 07   0.22258059E 08
R (KM  ) =     -0.31156519E 04  -0.66346500E 03   0.67842565E 04
V (KPS)  =     -0.55962263E 01  -0.38047438E 01  -0.27479349E 01

TIME (SEC) =      0.51600000E 05
R (FEET) =     -0.14313062E 08  -0.50865901E 07   0.19513916E 08
R (KM  ) =     -0.43626213E 04  -0.15503927E 04   0.59478416E 04
V (KPS)  =     -0.47531495E 01  -0.35553405E 01  -0.41877263E 01

TIME (SEC) =      0.51840000E 05
R (FEET) =     -0.17643007E 08  -0.77262247E 07   0.15728080E 08
R (KM  ) =     -0.53775886E 04  -0.23549533E 04   0.47939187E 04
V (KPS)  =     -0.36718845E 01  -0.31219329E 01  -0.53836756E 01

TIME (SEC) =      0.52080000E 05
R (FEET) =     -0.20048547E 08  -0.99612742E 07   0.11114960E 08
R (KM  ) =     -0.61107971E 04  -0.30361964E 04   0.33878397E 04
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V (KPS)    =   -0.24151358E 01  -0.25322684E 01  -0.62812747E 01

TIME (SEC) =     0.52320000E 05
R (FEET)   =   -0.21417948E 08  -0.11681693E 08   0.59250476E 07
R (KM  )   =   -0.65281906E 04  -0.35605801E 04   0.18059545E 04
V (KPS)    =   -0.10508211E 01  -0.18202415E 01  -0.68435482E 01

TIME (SEC) =     0.52560000E 05
R (FEET)   =   -0.21693732E 08  -0.12805763E 08   0.43118593E 06
R (KM  )   =   -0.66122494E 04  -0.39031967E 04   0.13142547E 03
V (KPS)    =    0.35148918E 00  -0.10237692E 01  -0.70510007E 01

TIME (SEC) =     0.52800000E 05
R (FEET)   =   -0.20872866E 08  -0.13282563E 08  -0.50849713E 07
R (KM  )   =   -0.63620497E 04  -0.40485251E 04  -0.15498992E 04
V (KPS)    =    0.17235902E 01  -0.18285749E 00  -0.69007979E 01

TIME (SEC) =     0.53040000E 05
R (FEET)   =   -0.19004761E 08  -0.13092985E 08  -0.10345668E 08
R (KM  )   =   -0.57926512E 04  -0.39907418E 04  -0.31533597E 04
V (KPS)    =    0.30010337E 01   0.66204669E 00  -0.64054592E 01

TIME (SEC) =     0.53280000E 05
R (FEET)   =   -0.16187530E 08  -0.12249537E 08  -0.15088619E 08
R (KM  )   =   -0.49339593E 04  -0.37336590E 04  -0.45990109E 04
V (KPS)    =    0.41249538E 01   0.14714002E 01  -0.55913581E 01

TIME (SEC) =     0.53520000E 05
R (FEET)   =   -0.12562973E 08  -0.10795159E 08  -0.19077355E 08
R (KM  )   =   -0.38291942E 04  -0.32903644E 04  -0.58147778E 04
V (KPS)    =    0.50434773E 01   0.22076549E 01  -0.44972604E 01

TIME (SEC) =     0.53760000E 05
R (FEET)   =   -0.83105817E 07  -0.88012621E 07  -0.22110402E 08
R (KM  )   =   -0.25330653E 04  -0.26826247E 04  -0.67392505E 04
V (KPS)    =    0.57120068E 01   0.28361872E 01  -0.31730207E 01
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TIME (SEC) =     0.54000000E 05
R (FEET) =    -0.36406359E 07  -0.63650610E 07  -0.24029514E 08
R (KM  ) =    -0.11096658E 04  -0.19400706E 04  -0.73241957E 04
V (KPS)  =     0.60989069E 01   0.33262051E 01  -0.16784143E 01

TIME (SEC) =     0.54240000E 05
R (FEET) =     0.12136306E 07  -0.36062063E 07  -0.24727003E 08
R (KM  ) =     0.36991460E 03  -0.10991717E 04  -0.75367904E 04
V (KPS)  =     0.61778383E 01   0.36517386E 01  -0.81989584E-01

TIME (SEC) =     0.54480000E 05
R (FEET) =     0.60050586E 07  -0.66252220E 06  -0.24152130E 08
R (KM  ) =     0.18303418E 04  -0.20193676E 03  -0.73615693E 04
V (KPS)  =     0.59383414E 01   0.37928236E 01   0.15403304E 01

TIME (SEC) =     0.54720000E 05
R (FEET) =     0.10482888E 08   0.23152072E 07  -0.22316244E 08
R (KM  ) =     0.31951843E 04   0.70567516E 03  -0.68019911E 04
V (KPS)  =     0.53831217E 01   0.37368950E 01   0.31071796E 01

TIME (SEC) =     0.54960000E 05
R (FEET) =     0.14404630E 08   0.51697312E 07  -0.19296038E 08
R (KM  ) =     0.43905311E 04   0.15757341E 04  -0.58814324E 04
V (KPS)  =     0.45307391E 01   0.34803467E 01   0.45346148E 01

TIME (SEC) =     0.55200000E 05
R (FEET) =     0.17549222E 08   0.77450480E 07  -0.15234027E 08
R (KM  ) =     0.53490027E 04   0.23606906E 04  -0.46433315E 04
V (KPS)  =     0.34170052E 01   0.30300639E 01   0.57401640E 01

TIME (SEC) =     0.55440000E 05
R (FEET) =     0.19730867E 08   0.98951812E 07  -0.10335296E 08
R (KM  ) =     0.60139681E 04   0.30160512E 04  -0.31501981E 04
V (KPS)  =     0.20954464E 01   0.24046189E 01   0.66481295E 01
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TIME (SEC) =     0.55680000E 05
R (FEET) =      0.20812571E 08   0.11493561E 08  -0.48597449E 07
R (KM  ) =      0.63436716E 04   0.35032375E 04  -0.14812502E 04
V (KPS)  =      0.63621618E 00   0.16347225E 01   0.71959004E 01

TIME (SEC) =     0.55920000E 05
R (FEET) =      0.20718076E 08   0.12442346E 08   0.89082126E 06
R (KM  ) =      0.63148695E 04   0.37924271E 04   0.27152232E 03
V (KPS)  =     -0.87714305E 00   0.76245809E 00   0.73405905E 01

TIME (SEC) =     0.56160000E 05
R (FEET) =      0.19440365E 08   0.12680550E 08   0.65904158E 07
R (KM  ) =      0.59254233E 04   0.38650315E 04   0.20087587E 04
V (KPS)  =     -0.23532146E 01  -0.16098847E 00   0.70647936E 01

TIME (SEC) =     0.56400000E 05
R (FEET) =      0.17045121E 08   0.12189850E 08   0.11910478E 08
R (KM  ) =      0.51953530E 04   0.37154663E 04   0.36303136E 04
V (KPS)  =     -0.37001284E 01  -0.10791151E 01   0.63801293E 01

STATION  FLOYD OBSERVES VEHICLE AT    0.55880000E 04   0.65277774E 00 DAYS
RELATIVE POSITION =   0.19245740E 07   0.10039124E 08  -0.23472491E 07
RELATIVE VELOCITY =  -0.11982695E 05  -0.46430115E 04   0.20932183E 05
R, RDOT, AZ, ELEV =   0.31967340E 04  -0.34527350E 01   0.11239295E 03   0.44354849E 01

TIME (SEC) =     0.56640000E 05
R (FEET) =      0.13668002E 08   0.10997000E 08   0.16542990E 08
R (KM  ) =      0.41660070E 04   0.33518856E 04   0.50423034E 04
V (KPS)  =     -0.48337492E 01  -0.19349122E 01   0.53274952E 01

STATION  FLOYD OBSERVES VEHICLE AT    0.55880000E 04   0.65555552E 00 DAYS
RELATIVE POSITION =  -0.14125920E 07   0.85819890E 07   0.22852635E 07
RELATIVE VELOCITY =  -0.15682652E 05  -0.74478314E 04   0.17478659E 05
R, RDOT, AZ, ELEV =   0.27409703E 04  -0.61710428E-01   0.78996670E 02   0.98444523E 01
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TIME (SEC) =     0.56880000E 05
R (FEET) =     0.95054770E 07    0.91722454E 07    0.20222681E 08
R (KM  ) =     0.28972694E 04    0.27957004E 04    0.61638732E 04
V (KPS)  =    -0.56852540E 01   -0.26759525E 01    0.39736558E 01

STATION  FLOYD OBSERVES VEHICLE AT     0.55880000E 04    0.65833329E 00 DAYS
RELATIVE POSITION =  -0.55305439E 07    0.64936886E 07    0.59649545E 07
RELATIVE VELOCITY =  -0.18457085E 05   -0.98758157E 04    0.13036929E 05
R, ROOT, AZ, ELEV =   0.31724920E 04    0.33885003E 01    0.45263802E 02    0.52222526E 01

TIME (SEC) =     0.57120000E 05
R (FEET) =     0.48004103E 07    0.68239356E 07    0.22745133E 08
R (KM  ) =     0.14631651E 04    0.20799356E 04    0.69327166E 04
V (KPS)  =    -0.62066515E 01   -0.32587760E 01    0.24048263E 01

TIME (SEC) =     0.57360000E 05
R (FEET) =    -0.17588611E 06    0.40900227E 07    0.23979106E 08
R (KM  ) =    -0.53610085E 02    0.12466389E 04    0.73088314E 04
V (KPS)  =    -0.63735576E 01   -0.35519538E 01    0.71851869E 00

TIME (SEC) =     0.57600000E 05
R (FEET) =    -0.51424841E 07    0.11278477E 07    0.23872002E 08
R (KM  ) =    -0.15674292E 04    0.34376798E 03    0.72761861E 04
V (KPS)  =    -0.61851841E 01   -0.38375179E 01   -0.98473005E 00

TIME (SEC) =     0.57840000E 05
R (FEET) =    -0.98266887E 07   -0.18965682E 07    0.22449118E 08
R (KM  ) =    -0.29951747E 04   -0.57807397E 03    0.68424910E 04
V (KPS)  =    -0.56621903E 01   -0.38109531E 01   -0.26086432E 01

TIME (SEC) =     0.58080000E 05
R (FEET) =    -0.13979524E 08   -0.48187229E 07    0.19807786E 08
R (KM  ) =    -0.42609590E 04   -0.14687467E 04    0.60374131E 04
V (KPS)  =    -0.48431839E 01   -0.35801125E 01   -0.40669072E 01

TIME (SEC) =     0.58320000E 05
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R (FEET) =    -0.17388060E 08  -0.74845851E 07   0.16107856E 08
R (KM  ) =    -0.52998807E 04  -0.22813015E 04   0.49096744E 04
V (KPS)  =    -0.37806048E 01  -0.31634675E 01  -0.52871352E 01

TIME (SEC) =   0.58560000E 05
R (FEET) =    -0.19884555E 08  -0.97581007E 07   0.11559739E 08
R (KM  ) =    -0.60608125E 04  -0.29742691E 04   0.35234086E 04
V (KPS)  =    -0.25364826E 01  -0.25880167E 01  -0.62133071E 01

TIME (SEC) =   0.58800000E 05
R (FEET) =    -0.21352365E 08  -0.11526991E 08   0.64111668E 07
R (KM  ) =    -0.65082009E 04  -0.35134269E 04   0.19541236E 04
V (KPS)  =    -0.11784151E 01  -0.18870920E 01  -0.68068619E 01

TIME (SEC) =   0.59040000E 05
R (FEET) =    -0.21728965E 08  -0.12706926E 08   0.93346987E 06
R (KM  ) =    -0.66229886E 04  -0.38730710E 04   0.28452161E 03
V (KPS)  =     0.22403712E 00  -0.10982330E 01  -0.70467389E 01

TIME (SEC) =   0.59280000E 05
R (FEET) =    -0.21006372E 08  -0.13244144E 08  -0.45920316E 07
R (KM  ) =    -0.64027423E 04  -0.40368152E 04  -0.13996512E 04
V (KPS)  =     0.16024264E 01  -0.26123102E 00  -0.69286213E 01

TIME (SEC) =   0.59520000E 05
R (FEET) =    -0.19229319E 08  -0.13116585E 08  -0.98867499E 07
R (KM  ) =    -0.58610963E 04  -0.39979352E 04  -0.30134814E 04
V (KPS)  =     0.28919456E 01   0.58352873E 00  -0.64636649E 01

TIME (SEC) =   0.59760000E 05
R (FEET) =    -0.16491656E 08  -0.12333800E 08  -0.14686587E 08
R (KM  ) =    -0.50266567E 04  -0.37593423E 04  -0.44764716E 04
V (KPS)  =     0.40328205E 01   0.13964472E 01  -0.56770096E 01

TIME (SEC) =   0.60000000E 05
R (FEET) =    -0.12931490E 08  -0.10935872E 08  -0.18752283E 08
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R (KM  ) =    -0.39415182E 04  -0.33332539E 04  -0.57156960E 04
V (KPS)  =     0.49727255E 01   0.21398022E 01  -0.46063284E 01

TIME (SEC) =     0.60240000E 05
R (FEET) =    -0.87252347E 07  -0.89915304E 07  -0.21878809E 08
R (KM  ) =    -0.26594515E 04  -0.27406184E 04  -0.66686611E 04
V (KPS)  =     0.56670105E 01   0.27787042E 01  -0.33005011E 01

TIME (SEC) =     0.60480000E 05
R (FEET) =    -0.40807968E 07  -0.65955491E 07  -0.23903642E 08
R (KM  ) =    -0.12438268E 04  -0.20103233E 04  -0.72858301E 04
V (KPS)  =     0.60803741E 01   0.32819955E 01  -0.18184461E 01

TIME (SEC) =     0.60720000E 05
R (FEET) =     0.77015368E 06  -0.38654621E 07  -0.24714187E 08
R (KM  ) =     0.23474284E 03  -0.11781928E 04  -0.75328841E 04
V (KPS)  =     0.61880837E 01   0.36232290E 01  -0.22798236E 00

TIME (SEC) =     0.60960000E 05
R (FEET) =     0.55810733E 07  -0.93743266E 06  -0.24254284E 08
R (KM  ) =     0.17011111E 04  -0.28572947E 03  -0.73927058E 04
V (KPS)  =     0.59775509E 01   0.37818339E 01   0.13955207E 01

TIME (SEC) =     0.61200000E 05
R (FEET) =     0.10100841E 08   0.20389237E 07  -0.22529500E 08
R (KM  ) =     0.30787363E 04   0.62146393E 03  -0.68669917E 04
V (KPS)  =     0.54501094E 01   0.37444994E 01   0.29710453E 01

TIME (SEC) =     0.61440000E 05
R (FEET) =     0.14085446E 08   0.49068517E 07  -0.19610593E 08
R (KM  ) =     0.42932441E 04   0.14956084E 04  -0.59773088E 04
V (KPS)  =     0.46228248E 01   0.35067226E 01   0.44146779E 01

TIME (SEC) =     0.61680000E 05
R (FEET) =     0.17311102E 08   0.75100924E 07  -0.15634273E 08
R (KM  ) =     0.52764240E 04   0.22890762E 04  -0.47653264E 04
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V (KPS)   =     0.35299487E 01   0.30743546E 01   0.56435641E 01

TIME (SEC) =     0.61920000E 05
R (FEET) =      0.19588053E 08   0.97015419E 07  -0.10800342E 08
R (KM  ) =      0.59704385E 04   0.29570299E 04  -0.32919443E 04
V (KPS)   =     0.22234991E 01   0.24648488E 01   0.65811061E 01

TIME (SEC) =     0.62160000E 05
R (FEET) =      0.20774259E 08   0.11352642E 08  -0.53643021E 07
R (KM  ) =      0.63319942E 04   0.34602852E 04  -0.16350393E 04
V (KPS)   =     0.77231153E 00   0.17077859E 01   0.71632324E 01

TIME (SEC) =     0.62400000E 05
R (FEET) =      0.20787507E 08   0.12362691E 08   0.37501629E 06
R (KM  ) =      0.63360320E 04   0.37681481E 04   0.11430496E 03
V (KPS)   =    -0.74097441E 00   0.84424578E 00   0.73450365E 01

TIME (SEC) =     0.62640000E 05
R (FEET) =      0.19614339E 08   0.12667157E 08   0.60928742E 07
R (KM  ) =      0.59784506E 04   0.38609496E 04   0.18571080E 04
V (KPS)   =    -0.22252711E 01  -0.75335639E-01   0.71066825E 01

STATION  FLØYD ØBSERVES VEHICLE AT    0.55880000E 04   0.72499996E 00 DAYS
RELATIVE PØSITIØN =   0.69775501E 07   0.40899699E 07  -0.81648526E 07
RELATIVE VELØCITY =  -0.66753000E 04  -0.11686534E 04   0.23315888E 05
R, RDØT, AZ, ELEV =   0.35029315E 04  -0.64109862E 01   0.18266666E 03   0.14410461E 01

TIME (SEC) =     0.62880000E 05
R (FEET) =      0.17314001E 08   0.12243723E 08   0.11459963E 08
R (KM  ) =      0.52773074E 04   0.37318867E 04   0.34929967E 04
V (KPS)   =    -0.35983391E 01  -0.99482693E 00   0.64571851E 01

STATION  FLØYD ØBSERVES VEHICLE AT    0.55880000E 04   0.72777773E 00 DAYS
RELATIVE PØSITIØN =   0.48292504E 07   0.34467009E 07  -0.27977639E 07
RELATIVE VELØCITY =  -0.11131277E 05  -0.41742702E 04   0.21194991E 05
R, RDØT, AZ, ELEV =   0.19993785E 04  -0.59204036E 01   0.17966298E 03   0.21529466E 02
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TIME (SEC) =      0.63120000E 05
R (FEET) =     0.14016246E 08   0.11115004E 08   0.16165530E 08
R (KM  ) =     0.42721516E 04   0.33878532E 04   0.49272537E 04
V (KPS)  =    -0.47449779E 01  -0.18571499E 01   0.54349597E 01

STATION  FLOYD OBSERVES VEHICLE AT    0.55880000E 04   0.73055551E 00 DAYS
RELATIVE POSITION =   0.16873485E 07   0.21008549E 07   0.19078037E 07
RELATIVE VELOCITY =  -0.14910191E 05  -0.69920490E 04   0.17831233E 05
R, RDOT, AZ, ELEV =   0.10063225E 04  -0.53817336E 00   0.11923635E 03   0.75937639E 02

TIME (SEC) =      0.63360000E 05
R (FEET) =     0.99127731E 07   0.93473636E 07   0.19939671E 08
R (KM  ) =     0.30214132E 04   0.28490764E 04   0.60776118E 04
V (KPS)  =    -0.56246987E 01  -0.26093533E 01   0.41047348E 01

STATION  FLOYD OBSERVES VEHICLE AT    0.55880000E 04   0.73333329E 00 DAYS
RELATIVE POSITION =  -0.22564?54E 07   0.11883500E 06   0.56819445E 07
RELATIVE VELOCITY =  -0.17780781E 05  -0.94482668E 04   0.13466978E 05
R, RDOT, AZ, ELEV =   0.18637801E 04   0.57581709E 01   0.15320919E 02   0.25509839E 02

TIME (SEC) =      0.63600000E 05
R (FEET) =     0.52431211E 07   0.70458097E 07   0.22572013E 08
R (KM  ) =     0.15981033E 04   0.21475623E 04   0.68799495E 04
V (KPS)  =    -0.61774909E 01  -0.32071089E 01   0.25513211E 01

STATION  FLOYD OBSERVES VEHICLE AT    0.55880000E 04   0.73611107E 00 D.YS
RELATIVE POSITION =  -0.67627714E 07  -0.23942718E 07   0.83142860E 07
RELATIVE VELOCITY =  -0.19578977E 05  -0.11397494E 05   0.83704761E 04
R, RDOT, AZ, ELEV =   0.33471837E 04   0.63641161E 01   0.12106679E 02   0.38729615E 01

TIME (SEC) =      0.63840000E 05
R (FEET) =     0.27696296E 06   0.43457581E 07   0.23924523E 08
R (KM  ) =     0.84418278E 02   0.13245871E 04   0.72921945E 04
V (KPS)  =    -0.63768328E 01  -0.36178867E 01   0.87155975E 00
```

SAMPLE PROBLEM

A sample problem was constructed around ECHO II tracking data recorddd at Floyd Satellite Communication Terminal. Floyd is located at the Rome Air Development Center in Rome, New York; more precisely, the station's coordinates are:

$$\lambda = 284.6596^\circ \text{ (east)}$$

$$\varphi = 43.1972^\circ \text{ (north)}$$

$$h = .164 \text{ km}$$

The osculating orbital elements for ECHO II at epoch 0 min (U. T.), 0 hours, 20 April 1965 were provided,

$$a = 7528.31 \text{ km}$$

$$e = .02447$$

$$i = 81.45^\circ$$

$$\omega = 34.156^\circ$$

$$\Omega = 31.202^\circ$$

$$M = 113.09\text{[illegible]}^\circ$$

and these were used to compute the position and velocity vectors at epoch in the geocentric coordinate system (true equinox of date).

$$\vec{R} = \begin{pmatrix} -59\text{[illegible]}5.\ 9438 \\ -2918.\ 1582 \\ 3783.\ 0742 \end{pmatrix} \text{ km}$$

$$\vec{V} = \begin{pmatrix} -2.744\ 4510 \\ -2.729\ 9969 \\ -6.074\ 8353 \end{pmatrix} \text{ km/sec.}$$

The position and velocity vectors were input into the general perturbations program (refer to Figure 2) and subsequent positions and velocities were predicted for a period of seven days at steps of 6480 seconds, approximately one revolution. During the eighth day, 27 April 1965, ECHO II was sighted several times by Floyd Tracking Station in New York. Consequently, at the beginning of the eighth day the step size in the program was cut to 60 seconds. After each step, the program tested to see if ECHO II was visible from Floyd Tracking Station. If the satellite is seen, the program outputs range, range-rate, azimuth, and elevation data. This computed data was compared with the observed data provided by RADC; the results for passes 6069 and 6070 are plotted in Figures 3 and 4.

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE ____ of ____ JOB NO. ______

Col.	Sign	NUMBER	Exp.	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	-	1940926 4	+08		x component of position (feet)
13	-	957400[illegible]8	+07		y
25		12411661	+08		z
37	-	9004104 3	+04		x component of velocity (fps)
49	-	89566827	+04	73 … 80	y
61	-	19930562	+05	DATA1111	z
1		5588	+04		whole number of days past 0^{th} 1 Jan. 1950.
13		0	+00		fractional part of day
25		1000	+04		step size (sec)
37		6912	+06		final elapsed time (sec)
49		10	+02	73 … 80	W/C_DA ($\#/ft^2$)
61		1	+01	DATA2222	number of tracking stations
1	F	LØYD b			station name
13		28465960	+03		longitude (deg, + east)
25		43197136	+02		latitude (deg, + north)
37		588.5	+03		altitude over $\frac{1}{298.3}$ spheroid (feet)
49		0	+00	73 … 80	horizon correction (deg)
61				DATA3333	
1					
13					
25					
37					
49				73 … 80	
61					

Form 114-C-17 Rev. 7-58 (Vellum)

FIGURE 2. INPUT DATA FOR SAMPLE PROBLEM

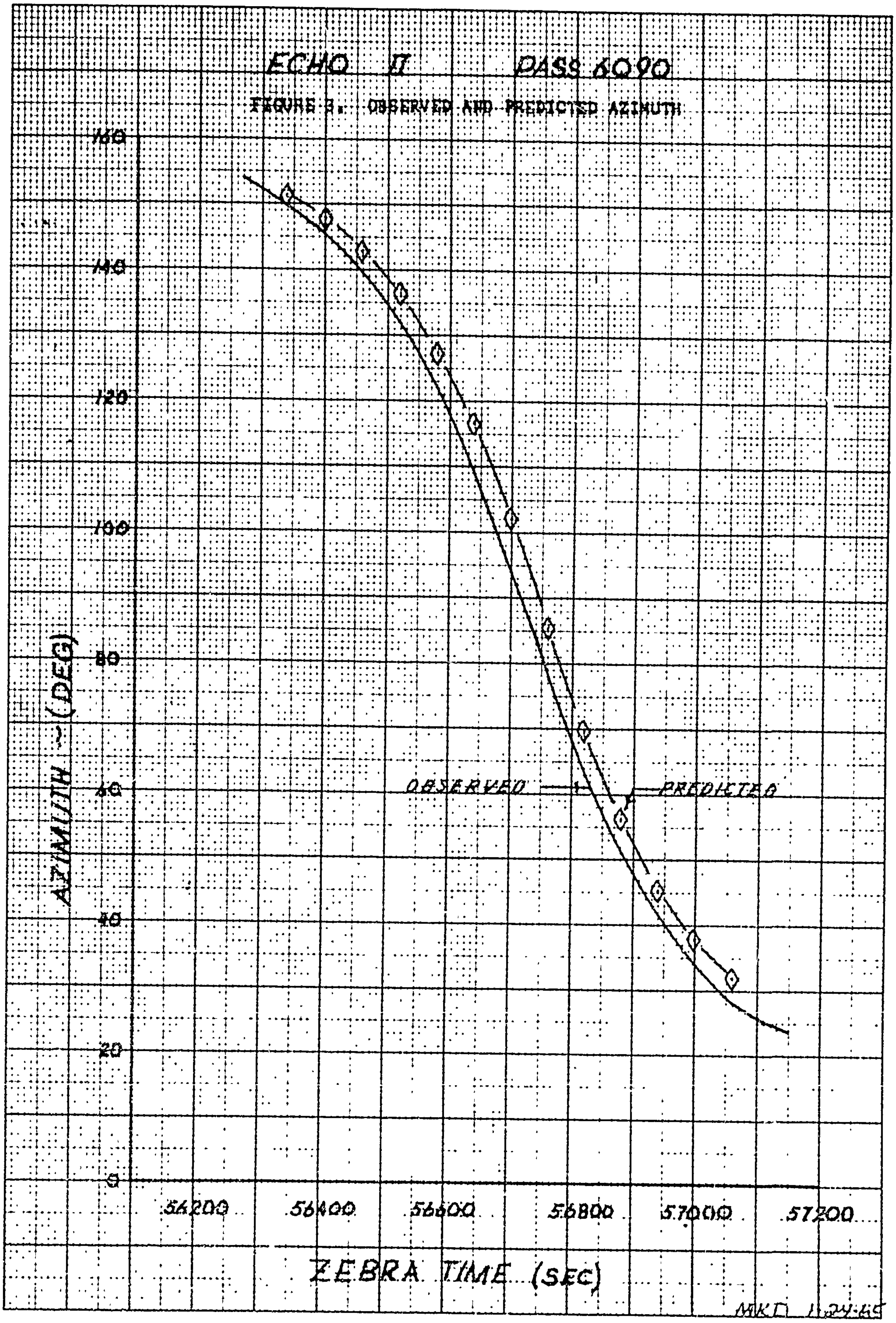
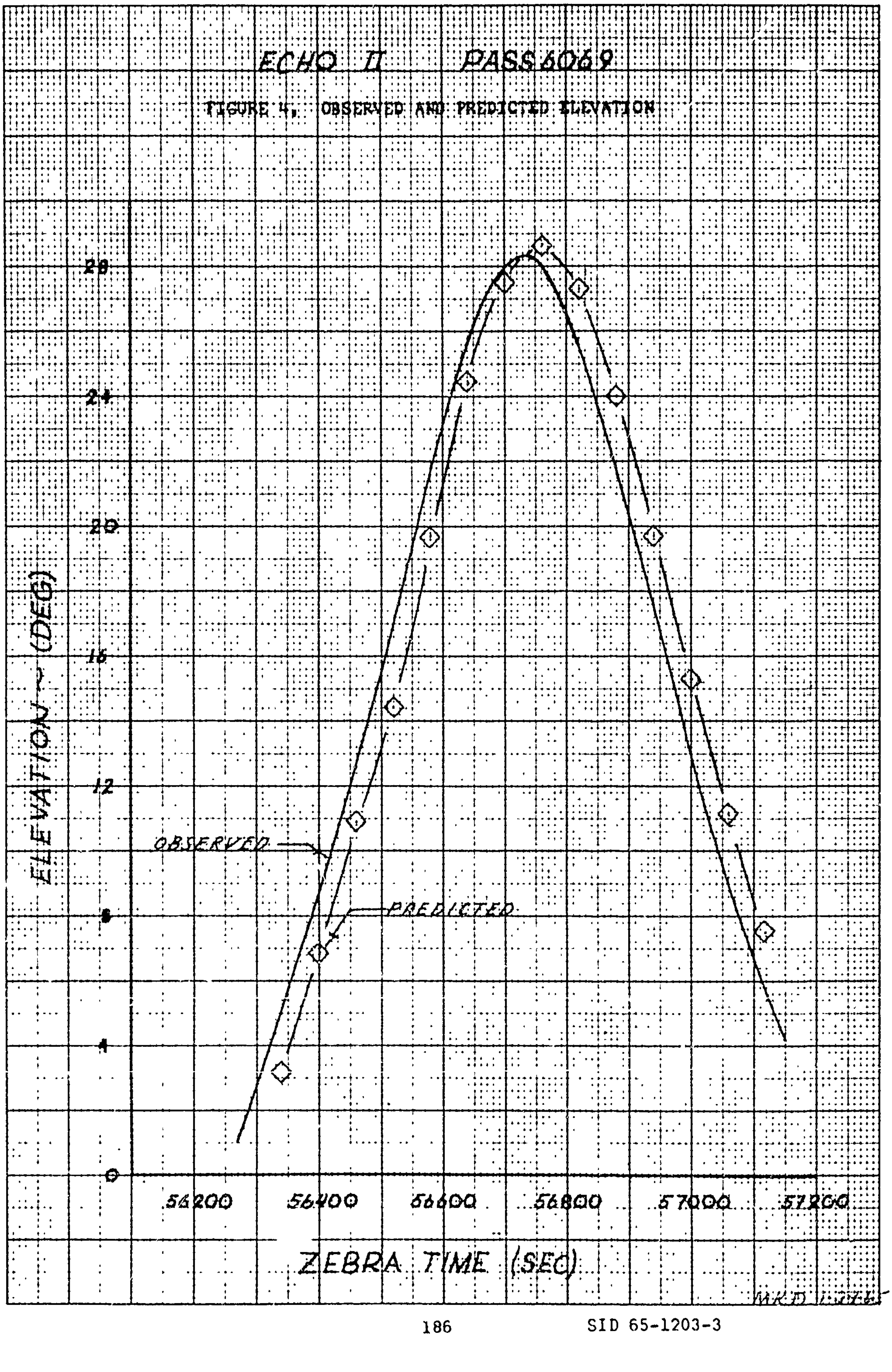


FIGURE 3. OBSERVED AND PREDICTED AZIMUTH


ECHO II PASS 6069
FIGURE 4. OBSERVED AND PREDICTED ELEVATION
ELEVATION ~ (DEG)
28
24
20
16
12
8
4
0
OBSERVED
PREDICTED
56200
56400
56600
56800
57000
57200
ZEBRA TIME (SEC)

Results of Sample Problem:

The Figures 3 and 4 present plots of observed and computed azimuth and elevation for the Echo II pass occurring at approximately the 16th hour of 27 April 1965. The curves show that during this eights day of prediction, the computed position logs the observed position by 20 to 30 seconds. Using a speed of about 8 km/sec, a corresponding position error of 160 to 240 km is indicated. The angular difference between the observed and predicted azimuth and elevations is on the order of ten degrees.

The time discrepancy of about 30 seconds after some 100 revolutions is approximately one-third of a second per revolution. The orbital period of Echo II is approximately 108 minutes (6480 seconds) so that the time discrepancy per period is one in the fifth significant figure. Since the initial osculating elements were to four or five significant figures, a difference of the above magnitude is to be expected.

ACCURACY TESTS

A check run was made against an Encke-type integrated trajectory generated by a North American, SID, digital computer program (AP-110). The comparison was made over three revolutions with an interval of four minutes between predicted points. To test more accurately the real-world effectiveness of the prediction program, all of the perturbations included in AP-110 were activated. Specifically, the oblateness through the fourth-order harmonics, drag, lunar and solar gravitational potentials were included. Because AP-120 predicts position in nautical miles, comparisons are made in these units. The table shows the position results after one, two and three revolutions. (G.P. denotes the general perturbation formulation.)

initial conditions:

	G.P.	AP-110
X	3600.0000	3600.0000
Y	0.0000	0.0000
Z	0.0000	0.0000

after one revolution:

	G.P.	AP-110
X	3596.53910	3596.53840
Y	-124.31783	-124.25333
Z	102.55489	-102.47667

after two revolutions:

	G.P.	AP-110
X	3586.24040	3586.17630
Y	-248.01990	-248.14364
Z	-204.60541	-204.69866

after three revolutions:

	G.P.	AP-110
X	3569.17900	3568.97940
Y	-370.89563	-371.66846
Z	-306.05043	-306.77181

The results indicate agreement with the integrated "real-world" trajectory to within one nautical mile after three revolutions.

CONCLUSIONS AND RECOMMENDATIONS

The accuracy test with an integrated Encke-type trajectory and the results of the sample problem have confirmed the soundness of this approach to the task of driving a tracking antenna in an open-loop mode.

The scope of the stody and the time restrictions have precluded an extensive checkout that would elevate the status of the FØRTRAN IV program to the all-inclusive level of "operation." Further checks on the variation of accuracy with prediction step size along with a complete incorporation and checkout of the differential corrections section would be necessary before the status promotion could be made.

Specifically, the following items merit consideration:

1. Increase program efficiency by combining groups of subroutines.
2. Increase program flexibility by including the effects of solar radiation pressure and lunar and solar gravitational potential.
3. Provide for initial-condition options, e.g. the non-singular osculating elements and/or a more conventional set of orbital elements.

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13. ABSTRACT

This document presents the formulation, computational logic and coding information developed for the purpose of effecting the definition of geocentric satellite orbits. The rationale for this process is constructed around the recursive minimum variance data filter developed by R. E. Kalman and a specially prepared magnetic tape generated in the preprocessor (SID 65 1203-2).

The trajectory portion of the program is formulated in the Encke manner and includes perturbing accelerations resulting from the first 3 harmonics of the Earth's potential function, atmospheric drag, solar radiation pressure,and solar and lunar gravitation. These accelerations are integrated via an uncorrected Gauss-Jackson routine started with a fourth order Runge-Kutta process.

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